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antarctic journal OF THE UNITED STATES

March 1982 National Science Foundation Volume XVII—Number 1

NSF photo by Russ Kinne.

Since 80 percent of antarctic sea ice melts each austral summer, the southern ocean is predominately covered by first-year replacement ice, which has an average thickness of about 1.5 meters. Although sea ice makes navigation in polar waters hazardous all year, the antarctic summer icepack with its more uniform thickness is generally more navigable by icebreaker than arctic icepack, which is composed of older and more complex forms of ice. The photograph shows broken pack ice north of Ross Island.

Antarctic sea ice analysis and forecasting

Sea ice is an enemy of the ship master or mate. During the polar winter, sea ice is found in concentrations and thicknesses unnavigable by ships. In the Antarctic the winter sea ice cover, surrounding the continent, grows to a maximum of 20 million square kilometers. In the Arctic 11.7 million square kilometers of winter sea ice limit ship movements to icebreaker-assisted operations along the fringes of the ice pack. During the summer breakup pack ice decays rapidly with meltwater percolating through the floes creating "rotten ice." Antarctic sea ice recedes during the austral summer to 4 million square kilometers (20 percent of its maximum)—a dramatic change in comparison to arctic sea ice that recedes to 5.2 million square kilometers (about 45 percent of its maximum) with much of the ice surviving the summer melt.

Travel in polar waters, covered by easily broken, rotten ice, requires close observation of changing ice conditions. Even a seasoned ship-handler, transiting these waters, can be lulled into a false sense of security. Unobserved within the pack may be such hazards as a multiyear floe known to seamen as blue ice. This multiyear ice is thick and fresh, having survived at least two seasonal melts and undisturbed may grow to be 3 to 4 meters thick.

Charting the distribution and movement of antarctic and arctic sea ice is the responsibility of the U.S. Navy-National Oceanic and Atmospheric Administration Joint Ice Center (JIC) which has been in existence since 1976. Operating from the Naval Polar Oceanography Center in Suitland, Maryland, the JIC also provides ice analysis and forecasting services for the U.S. Great Lakes. These analyses use data primarily from polar-orbiting satellites and are considered critical for safe polar navigation in both polar hemispheres. In addition, increased knowledge of sea ice distribution is imperative for the further improvement of numerical models used in

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weather forecasting and for a better understanding of global climate.

In the Antarctic, accurate knowledge of ice conditions can save thousands of dollars in fuel by enabling ships to navigate the most efficient and expedient route to destinations. More importantly, this knowledge can enhance the safety and survival of ships. As evidenced by the December 1981 sinking of the West German research vessel *Gotland II* off Cape Adare in Victoria Land, dense sea ice can be dangerous—especially when under dynamic pressure.

Although sea ice presents a substantial danger to shipping, routine observations and forecasting of seasonal and daily ice conditions were not begun until the 1950's. In the late 1940's U.S. Navy ships, transporting construction materials to U.S. arctic stations, incurred millions of dollars of damage from sea ice. These losses spurred the development of a naval ice observation and forecasting program. The Naval Oceanographic Office was the first Navy organization tasked with the sea-ice forecasting program. In 1954, the Naval Weather Service began training aerographer's mates to observe sea ice, and in 1963 short-range operational sea-ice forecasting became a Naval Weather Service responsibility. For the next 7 years, the Naval Weather Service conducted its ice operations from the Fleet Weather Central in Kodiak, Alaska, and the Fleet Weather Facility in Argentia, Newfoundland.

Editor: Winifred Reuning

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The Director of the National Science Foundation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this agency. Use of funds for printing this periodical has been approved by the director of the Office of Management and Budget through 31 March 1984.

In 1970, forecasting was centralized at the Naval Polar Oceanography Center, then known as the Fleet Weather Facility, Suitland, and became a global effort with the addition of antarctic responsibilities. The Suitland location brought together the resources of the National Environmental Satellite Service, the National Meteorological Center, and the Fleet Weather Facility and provided sea ice observers with immediate access to satellite imagery and meteorological charts. Today, the JIC employs 2 naval officers, 18 enlisted specialists, and 3 civilians. Additionally, two NOAA civilians from the National Earth Satellite Service and the National Weather Service participate as an analyst and a supervisor.

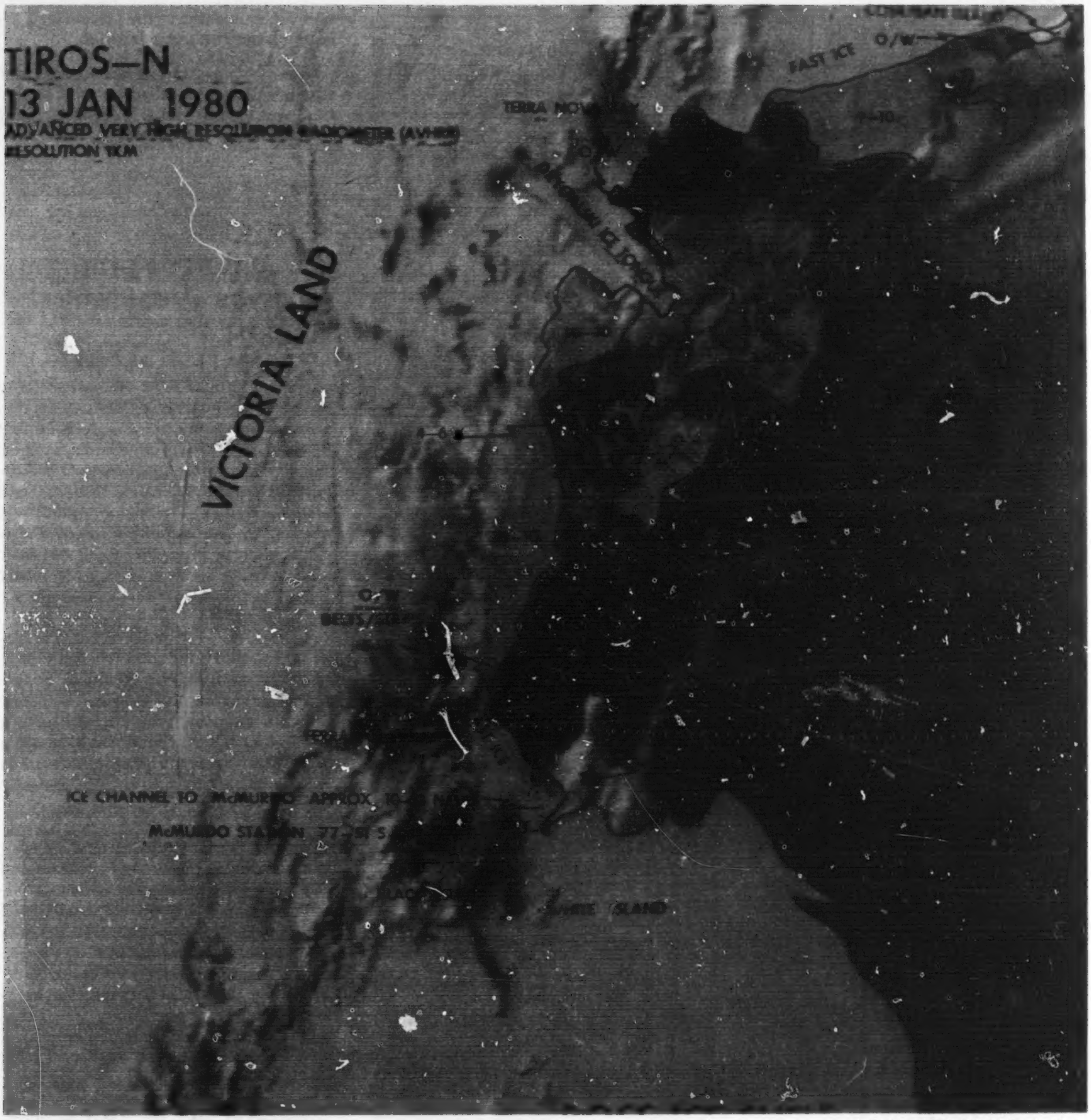
Satellite data from the National Earth Satellite Service in Suitland, the Air Force Global Weather Central in Omaha, Nebraska (by way of the Pentagon), the Fleet Numerical Oceanography Center in Monterey, California (via an on-board interactive computer called the Naval Environmental Display Station), and NASA's Goddard Space Flight Center in Greenbelt, Maryland, ensure access to most available data for analysis. Global ship reports and U.S. and foreign aerial reconnaissance data are also available through Navy and NOAA communication circuits. Current meteorological charts and forecasts from the National Meteorological Center in Suitland and the Fleet Numerical Oceanography Center are factored into the preparation of ice forecasts.

Satellite imagery is the most important data source for the effective global analysis of sea ice. Sensors aboard the various satellites respond or are sensitive to radiation from different portions of the electromagnetic spectrum. The physical properties of sea ice cause the ice to emit or reflect radiation in specific ways (different types of sea ice have different electromagnetic signatures) that an analyst can exploit. Limited high-resolution (1 kilometer) visual and infrared imagery from NOAA polar orbiting satellites provides detailed information on inner pack ice conditions and ice types critical to research and shipping operations. By analyzing differences in the reflectivity and thermal characteristics of the imagery, information relating to concentration and type of sea ice can be mapped. Visual and infrared imagery cannot see through clouds, but this restriction can be overcome using low resolution (25 kilometers) passive microwave imagery from the Nimbus 5 and 7 polar-orbiting satellites. Microwave radiation, not affected by clouds, can be detected by the satellite sensor in any weather.

Manual techniques also are used in sea ice forecasting. JIC specialists superimpose a chart of forecast surface winds on the existing edge and inner pack concentrations and then "move" or advect the ice at a rate of 1 to 3 percent of the wind speed and at an angle of approximately 30 degrees to the right of the true wind in the Northern Hemisphere or 30 degrees to the left of the true wind in the Southern Hemisphere. The angle is varied according to ice concentration and roughness. Ocean currents also are significant and are incorporated into the final ice forecast.

Another important consideration is temperature. When cold winds blow off the continental land masses of the Arctic or the antarctic continent in early fall, sea water cools rapidly. When it has uniformly cooled to the brink of freezing (29° Fahrenheit or -1.6° Celcius), rapid growth of ice over large expanses of ocean is possible and must be considered in preparation of the forecast. Computer guidance, in the form of ice drift vectors, is available for the arctic seas. The vectors are computed from a simple one-dimensional empirical algorithm. A naval research group has almost completed work on a two-dimensional dynamic/thermodynamic numerical model for the Arctic Ocean. This model will include sea ice forecasts through growth, advection, and decay stages. A similar numerical model also is planned for antarctic waters.

During the austral summer, aerial ice reconnaissance and forecasting personnel are deployed from Suitland to McMurdo Station, Antarctica, to provide support to the United States Antarctic Program. These ice forecasters prepare analyses and forecasts using satellite imagery received directly at McMurdo Station to augment ice information received from the JIC in Suitland and from ice-reconnaissance flights over the Ross Sea. After incorporating all available ship observations, the ice information is disseminated through facsimile broadcast and naval message from McMurdo Station. Ice information from the JIC is transmitted to Palmer Station near the Antarctic Peninsula for rebroadcast to ships operating between 90°W and 20°E. In addition to providing direct support to ships of the U.S. Coast Guard and Military Sealift Command, the JIC regularly provides direct support to vessels such as Argentina's *Irizar*, Japan's *Fuji*, South Africa's *Agul-*


TIROS—N
13 JAN 1980
ADVANCED VERY HIGH RESOLUTION RADIOMETER (AVHRR)
RESOLUTION 1KM
VICTORIA LAND
FAST ICE
O/W
TERRA NOVA BAY
ICE TONGUE
9-10
O/W
ICE CHANNEL TO McMURDO APPROX.
McMURDO STATION 77-51 S
WHITE ISLAND

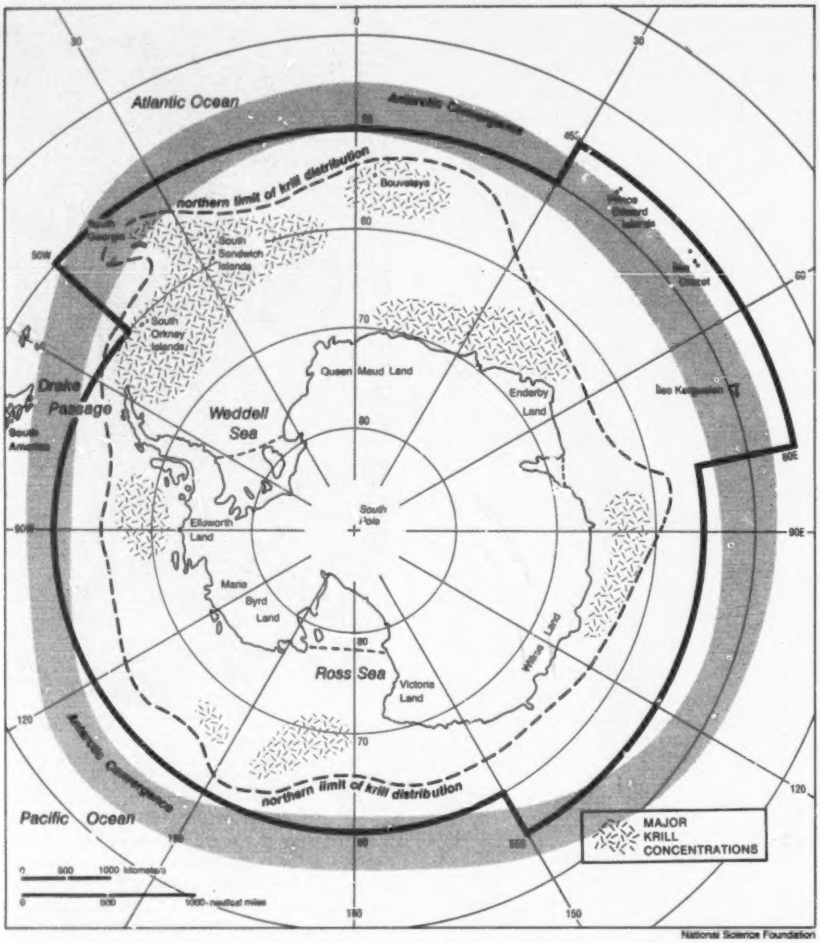
U. S. Navy-NOAA Joint Ice Center photo.

High-resolution visual and infrared imagery from National Oceanic and Atmospheric Administration polar orbiting satellites provides detailed information on inner pack ice conditions and ice types critical to research and shipping operations. This Advanced Very High Resolution Radiometer image taken by TIROS-N on 13 January 1980 shows the ice edge near Ross Island and along the coast of southern Victoria Land. Satellite imagery such as this helps analysts and forecasters to map changing sea ice conditions. Numbers show ice concentration in tenths, and o/w means "open water." The lines identifying the ice limits were provided by the Joint Ice Center.

has, and research and resupply ships supporting the French station Dumont D'Urville and Australia's Casey Station. Other countries routinely supported include Great Britain, West Germany, and New Zealand.

In the future, the keys to better sea-ice analysis and forecasting will be new-generation satellites and advances in computer technology. Future satellite systems will have improved resolution in all portions of the electromagnetic spectrum. The satellite data will be digitally manipulated at the Joint Ice Center to extract all the available ice information from the imagery. Techniques using interactive computers, such as image enhancement and superposition of data fields, will greatly increase the interpretive capability of the analyst. Finally, more sophisticated and improved numerical ice models will result in the greater accuracy of sea ice forecasts.

—Manuel G. Salinas, Lieutenant Commander, U.S. Navy, Naval Polar Oceanography Center, Suitland, Maryland.


Atlantic Ocean
Antarctic Convergence
northern limit of krill distribution
Bouvetøya
South Georgia
South Sandwich Islands
South Orkney Islands
Drake Passage
South America
Weddell Sea
Queen Maud Land
Enderby Land
Prince Edward Islands
Îles Crozet
Îles Kerguelen
Ellsworth Land
South Pole
Marie Byrd Land
Ross Sea
Victoria Land
Wilkes Land
Pacific Ocean
MAJOR KRILL CONCENTRATIONS
0 500 1000 kilometers
0 500 1000 nautical miles
0
30
30
50W
60
90W
90E
120
120
150
180
150
60
70
80
80
70
60
45S
50E
55S

National Science Foundation

The boundary (solid line) of the Convention on the Conservation of Antarctic Marine Living Resources is determined by the approximate location of the Antarctic Convergence (shaded area). Within this area the convention protects all species of marine organisms and establishes a standard for rational use of these resources. By designating all populations, not just harvested ones, as resources the convention recognizes the interdependence of the components of the antarctic marine ecosystem.

April 1982 marks beginning of antarctic marine conservation regime

The Convention on the Conservation of Antarctic Marine Living Resources, signed by 15 nations in May 1980, entered into force on 7 April 1982, upon ratification by 8 of these 15 signatories. The United States became the seventh ratifying nation when the U.S. instrument of ratification was signed by the President in February 1982. The decisive eighth ratification was made by New Zealand in March 1982.

The six nations that ratified the convention in 1981 are Australia, Japan, the Soviet Union, Chile, South Africa, and the United Kingdom (all consultative parties to the Antarctic Treaty). Upon ratification, each of the nations became a contracting party to the convention.

The convention establishes a conservation standard to ensure the continued health of individual species of antarctic marine organisms and defines rational use of these resources as actions that will not disturb the ecosystem's balance. This standard applies not only to the area south of 60° South latitude, which is covered by the Antarctic Treaty, but also to the area between 60°S and the Antarctic Convergence (see map above). The text of the convention was published in the December 1980 issue of the *Antarctic Journal*.

The first meeting of the Convention Commission, established by the Convention, was held in Hobart, Australia, from 25 May to 11 June 1982.

U.S. antarctic program receives Presidential support

In a 5 February 1982 memorandum to executive agencies the President of the United States announced his decision that the United States will continue to support an active and influential presence in Antarctica through scientific research and related activities. The memorandum was prepared in keeping with a recent review of the antarctic program by the Antarctic Policy Group, an interagency committee chaired by the Department of State.

As the President has directed, the National Science Foundation will continue to budget for and the manage the U. S. antarctic program, including support activities. The U.S. antarctic program will include the conduct of science research in all major disciplines. Year-round stations will be maintained at the South Pole and two coastal locations.

During its study the Antarctic Policy Group reviewed the current program and proposals for future U.S. antarctic activities. Their final analysis emphasized the need to maintain a balanced research program in Antarctica as the best way to express U.S. national interests in the continent. They also stated that program management by the Foundation, which has been responsible for managing and funding the program since 1972, was the most cost effective system.

Founded in 1965, the Antarctic Policy Group provides policy guidance for all U.S. activities under the Antarctic Treaty and reviews U.S. activities in Antarctica each year on a schedule coordinated with budget decisions. The National Science Foundation along with the Departments of State and Defense are permanent members of the policy-making group; 13 other government organizations are *ad hoc* members. Their 1970 review resulted in the consolidation of planning, funding, and management of the antarctic program in a single package at the National Science Foundation.

The text of the President's memorandum, follows this article.

President's Memorandum

The White House
Washington

February 5, 1982

Memorandum for:

The Secretary of State
The Secretary of Treasury
The Secretary of Defense
The Secretary of the Interior
The Secretary of Commerce
The Secretary of Transportation
The Secretary of Energy
The Director, Office of Management and Budget
The Director of Central Intelligence
Chairman, Joint Chiefs of Staff
Director, Arms Control and Disarmament Agency
Director, Office of Science and Technology Policy
Administrator, Environmental Protection Agency
Director, National Science Foundation

Subject: United States Antarctic Policy and Programs

"I have reviewed the Antarctic Policy Group's study of United States interests in Antarctica and related policy and program considerations, as forwarded by the Department of State on November 13, 1981, and have decided that:

"The United States Antarctic Program shall be maintained at a level providing an active and influential presence in Antarctica designed to support the range of U.S. Antarctic interests.

"This presence shall include the conduct of scientific activities in major disciplines; year-round occupation of the South Pole and two coastal stations; and availability of related necessary logistics support.

"Every effort shall be made to manage the program in a manner that maximizes cost effectiveness and return on investment.

"I have also decided that the National Science Foundation shall continue to:

- budget for and manage the entire United States national program in Antarctica, including logistic support activities so that the program may be managed as a single package;
- fund university research and federal agency programs related to Antarctica;
- draw upon logistic support capabilities of government agencies on a cost reimbursable basis; and
- use commercial support and management facilities where these are determined to be cost effective and will not, in the view of the Group, be detrimental to the national interest.

"Other agencies may, however, fund and undertake directed short-term programs of scientific activity related to Antarctica upon the recommendation of the Antarctic Policy Group and subject to the budgetary review process. Such activities shall be coordinated within the framework of the National Science Foundation logistics support.

"The expenditures and commitment of resources necessary to maintain an active and influential presence in Antarctica, including the scientific activities and stations in the Antarctic, shall be reviewed and determined as part of the normal budget process. To ensure that the United States Antarctic Program is not funded at the expense of other National Science Foundation programs, the OMB will provide specific budgetary guidance for the Antarctic program.

"To ensure that the United States has the necessary flexibility and operational reach in the area, the Departments of Defense and Transportation shall continue to provide, on a reimbursable basis, the logistic support requested by the National Science Foundation and to develop, in collaboration with the Foundation, logistic arrangements and cost structure required for effective and responsive program support at minimum cost.

"With respect to the upcoming negotiations on a regime covering Antarctic mineral resources, the Antarctic Policy Group shall prepare a detailed U.S. position and instructions. These should be forwarded for my consideration by May 15, 1982."

(Signed) Ronald Reagan

Antarctic Conservation Act permit applications due

The Antarctic Conservation Act became effective on 1 July 1979. Under this Act permits are required for certain activities in Antarctica. Regulations (published in the June 1979 issue of the *Antarctic Journal*) have been implemented to conserve and protect mammals, birds, and plants native to Antarctica and to preserve the ecosystem.

For the 1980-1981 season 12 permits were issued, and for the 1981-1982 season 16 were issued. The activities covered by the permits included capturing birds and seals for study in Antarctica or the United States, introducing fish to Antarctica for laboratory experiments, and collecting geological samples in Specially Protected Areas and Sites of Special Scientific Interest.

U. S. Navy photo (780111) by Douglas K. Nortell.

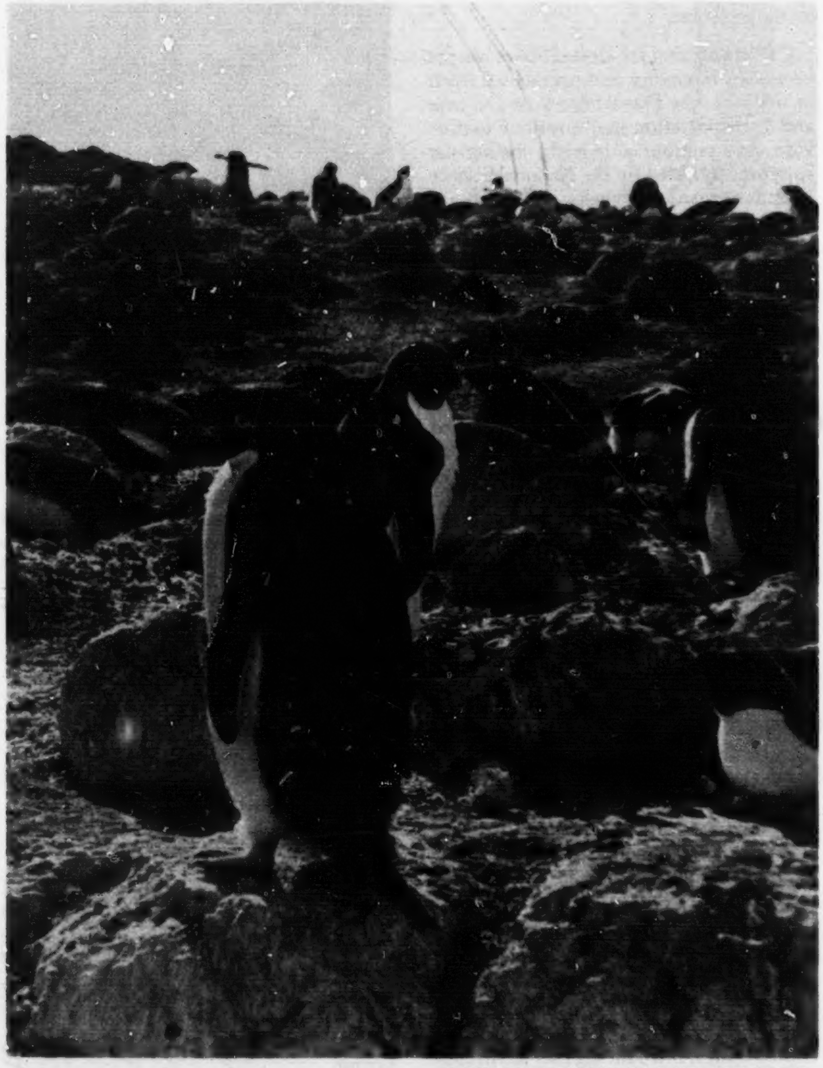
Elmer Birney of the University of Minnesota tags a Weddell seal pup, while Harry Phillips holds the seal's flipper. University of Minnesota graduate student Jan Eldridge prepares another tag. Tagging helps biologists study the movement, population changes, and reproduction and feeding habits of seals, but such research activities require Antarctic Conservation Act permits.

Specially Protected Areas are areas of outstanding environmental interest, while Sites of Special Scientific Interest are areas of unique scientific value requiring protection from interference. The 14 Specially Protected Areas, designated by the Director of the National Science Foundation, were identified by the Antarctic Treaty consultative parties in the "Agreed Measures for the Conservation of Antarctic Fauna and Flora," developed in 1964. Sites of Special Scientific Interest are those approved by the United States in accordance with recommendations made at the Eighth Antarctic Treaty Consultative Meeting and designated by the Director of the National Science Foundation. Entry into specially protected areas and certain sites of special scientific interest is prohibited without a permit.

The National Science Foundation initiated the permit system in response to the Antarctic Conservation Act, which implements the 1964 Agreed Measures. Besides entry into the designated specially protected areas, permits are required if researchers intend to take any native antarctic mammal or bird during research. In the Act, the definition of "to take" includes to remove, harass, molest, harm, pursue, hunt, shoot, wound, kill, trap, capture, restrain, or tag native mammals or birds or to attempt to do any of these activities. Collecting native plants in specially protected areas, importing into or exporting from the United States any native antarctic bird, mammal, or plant, and introducing any nonindigenous plant or animal also require permits under the Act's regulations.

Applications are evaluated on the basis of the Conservation Act objectives. After an application is approved, a permit will be issued by the Director of the National Science Foundation. Violators of the act are subject to heavy fines (up to $10,000) and/or 1-year imprisonment.

If there is doubt as to whether a 1982-1983 project requires a permit, researchers should contact the Division of Polar Programs as soon as possible. A booklet, containing a copy of the law with regulations, permit forms, and instructions is available from the Permit Office, Division of Polar Programs, National Science Foundation, Washington, D.C. 20550.



U. S. Navy photo (XAM-0529-B-12-80) by Brad F. Guttilla.

This Adelie penguin rookery at Cape Royds, Ross Island, is the southernmost known colony of this penguin species. The penguins are protected by the Antarctic Conservation Act. A permit is required before scientists can conduct research at Cape Royds, one of eight Sites of Special Scientific Interest.

New source of ultra-low-frequency waves discovered

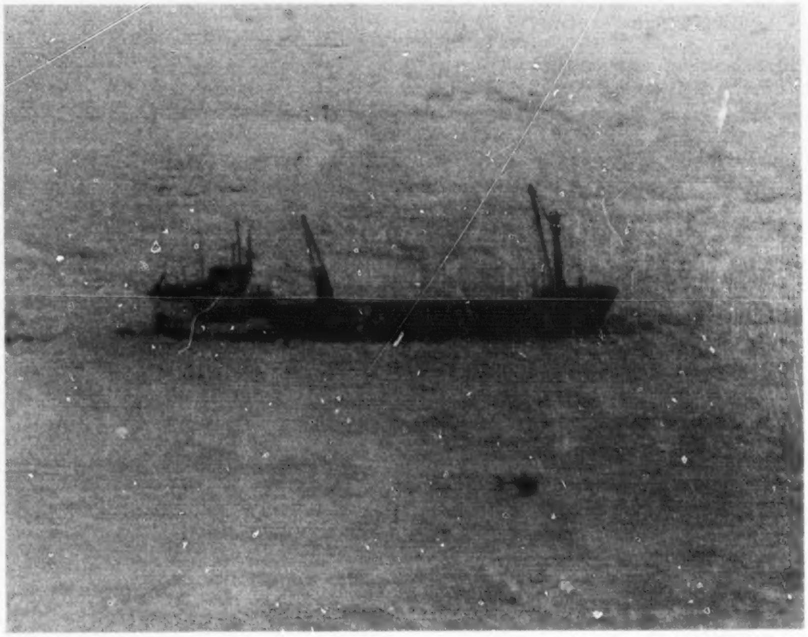
Data acquired at Siple Station, Antarctica, and stations in the northern hemisphere over the last 3 years enabled Theodore J. Rosenberg and Peter B. Morris of the University of Maryland and Louis J. Lanzerotti of Bell Laboratories in Murray Hill, New Jersey, to discover a previously unknown source of ultra-low-frequency (ULF) waves in the earth's upper atmosphere. Their discovery links solar flares, temporary eruptions of solar gases from small areas of the sun's surface, with the occurrence of ULF waves in the ionosphere. Before this discovery, atmospheric physicists believed that naturally occurring ULF waves were generated by the interaction between the solar wind and the earth's magnetic field and from discharges within the magnetosphere during magnetic storms. ULF waves have a frequency of less than 10 cycles per second.

The ionosphere is that part of the upper atmosphere which begins about 80 kilometers above the earth and extends outward 560 to 965 kilometers. This region, which forms the base of the magnetosphere, is composed of electrically charged particles which reflect radio waves and make possible long-distance communications. The magnetosphere begins about 100 kilometers above the earth. Shaped like a giant comet, the magnetosphere has a long tail, extending several million kilometers into space and pointing away from the sun. The side facing the sun is relatively blunt and reaches 64,000 kilometers above the earth. In this region, the solar wind, streams of electrons and protons flowing from the sun, is trapped and deformed by the earth's geomagnetic field.

Drs. Rosenberg and Lanzerotti and Mr. Morris found that when ionization of the ionosphere is increased by ultraviolet light and x-rays from solar flares, the conductivity of the ionosphere is increased, and ULF waves are generated. At ground stations the scientists used magnetometers and riometers to obtain data. A magnetometer measures the fluctuations in the magnitude and direction of the earth's magnetic field. A riometer or relative ionospheric opacity meter measures the ability of the ionosphere to absorb electromagnetic waves by determining and recording the levels of cosmic radio noise.

Data were gathered at Siple Station and four stations in the northern hemisphere, two in Quebec, Canada, and two in New Hampshire. Siple Station, 1,290 kilometers from the South Pole at the base of the Antarctic Peninsula, is at the end of one geomagnetic line of force that passes outward through the magnetosphere and returns to earth in the northern hemisphere at what is called its conjugate point, near the four stations. At Siple Station there also is little electromagnetic disturbance. By correlating magnetometer and riometer data taken at the five stations with data on solar flares from satellites, the scientists were able to locate the new source of ULF waves.

This discovery will help scientists understand both the structure of the magnetosphere and the ionosphere, and the interaction between these two regions that surround the earth. Besides being of fundamental scientific importance, ULF waves can be used to predict the occurrence of magnetic storms that can disrupt electric power systems on a large scale and cause outages in long-distance communications. Because these waves penetrate the earth, they also are useful in studying the earth's crust and upper mantle. Drs. Rosenberg and Lanzerotti and Mr. Morris have published the results of their work in the *Physical Review Letters*, one of the journals of the American Physical Society.



U. S. Navy photo by Gordon M. Sobe.

The West German ship *Gotland II* beset off Cape Adare. The photograph was taken from a U. S. LC-130 airplane several hours before the ship sank. In the foreground is one of the Hughes 500 helicopters used to transport scientists and crew to safety and later to a U. S. camp in northern Victoria Land.

U.S. aids West German research party

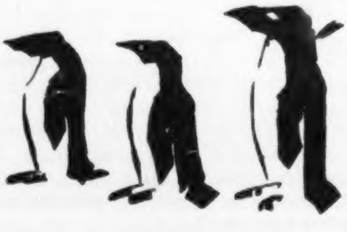
During the afternoon of 18 December 1981, the West German research ship *Gotland II* sank off the coast of northern Victoria Land. The 93-meter, ice-strengthened *Gotland II* was in this region to support West German scientists investigating the geology and geophysics of northern Victoria Land. The program was to be a continuation of research begun during the 1979-1980 austral summer.

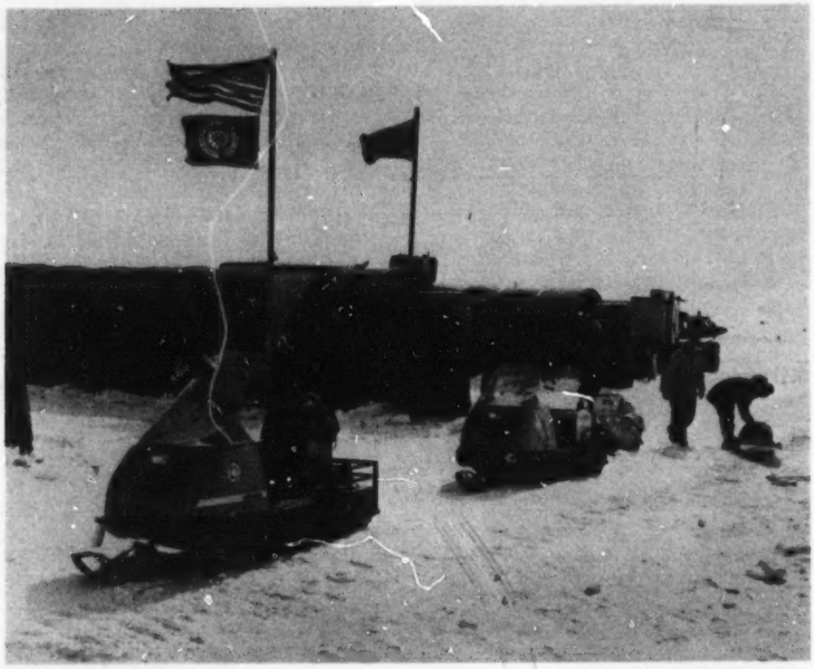
On 17 December, McMurdo Station personnel received word, relayed from a U.S. field camp in northern Victoria Land, that the 4,400-ton ship was trapped in the pack ice in Yule Bay (70°44'S 166°40'E). Further communication revealed that the ship's starboard side had been bent by the pressure of the ice, and a leak had developed in the hold. The captain had immediately evacuated 27 of the 41 crew members and passengers, including the West German scientific party, to a coastal camp known as Birthday Ridge Camp, approximately 120 miles from the U.S. field camp in northern Victoria Land.

At first no emergency assistance was requested because the emergency discharge pumps onboard seemed to be controlling the amount of water entering the hold. Several hours later, the captain reported that the water level in the ship's hold was rising at a rapid rate, the pumps could not keep up with it, and water prevented the crew from reaching the leak to repair it. At this point all but four crew members were evacuated to the camp. Additional pumps, requested from McMurdo Station, were transported and airdropped by U.S. Hercules craft a few hours later, but before the pumps were put into operation the ship's main deck was flooded.

All 41 crew members and scientists were safely evacuated by the expeditious Hughes 500 helicopters along with equipment and supplies and moved to one camp near Lillie Glacier (70°45'S 163°55'E) and two temporary camps nearby. Later the helicopters moved all personnel and some critical equipment to the U.S. field camp near the Canham Glacier (approximately 71°49'S 163°E). From this location they were flown to McMurdo Station by U.S. LC-130 aircraft. The USNS *Southern Cross*, McMurdo's annual resupply ship, took the helicopters on its regular return trip to Port Hueneme, California, where their owner retrieved them.

Although many ships have been trapped, the *Gotland II* was only the third ship known to be crushed and sunk in Antarctic pack ice. In 1903 the Norwegian whaling ship *Antarctic*, which was supporting a Swedish exploration party on Snow Island near the Antarctic Peninsula, was locked in the ice floes and carried by the wind and ice for over a month before the ship sank off Paulet Island. Twelve years later in October 1915, the *Endurance*, carrying Ernest Shackleton's party, was beset and sank a month later. The stranded men eventually reached Elephant Island from which Shackleton and 4 others began a journey in a make-shift boat across the southern ocean to South Georgia Island to find help for the rest of the party.





NSF photo by Russ Kinne.

Five Jamesways—prefabricated, wood-framed and wood-floored buildings covered with insulated canvas blankets—provided living quarters, galley facilities, work spaces, and a helicopter maintenance area for scientists and support personnel at the northern Victoria Land base camp. Field parties used motor toboggans and sleds for transportation.

Northern Victoria Land expedition, 1981-1982

On 24 October 1981, an LC-130 airplane brought construction workers from McMurdo Station to a site in northern Victoria Land to set up a field camp. During the next 2 weeks these workers under the direction of Allan Priddy and other employees of Antarctic Services, Inc., the USARP support contractor, erected a plywood generator hut and five Jamesway buildings (see photograph above).

On 6 November the first scientists and technicians arrived at the camp, 600 kilometers north of McMurdo Station, Ross Island. Between 9 November (when science flights began) and 13 January 1982, 63 researchers from four countries (United States, New Zealand, Australia, and West Germany) participated in 22 projects focused on the geology and geophysics of the region. During this time these scientists and technicians investigated an area that extended to the polar plateau on the west, the sea on the north and south, and almost to Hallett Station (72°19'S 170°13'E) on the east—185 kilometers or 100 nautical miles in radius. The chief scientist for the expedition Edmund Stump, of Arizona State University, established scientific priorities, and ANS, Inc. employee Philip V. Colbert was camp manager.

Three UH-1N helicopters along with motor toboggans were used for local transportation. John Splettstoesser of the Minnesota Geological Survey arranged and coordinated daily flight schedules in consultation with Navy helicopter pilots and participating scientists. Investigators used motor toboggans extensively in the field and were able to continue field work, even when poor weather prevented helicopter flights.

Northern Victoria Land is made up of high mountain ranges forming the northern end of the Transantarctic Mountains. One of the expedition's objectives was to provide information for more accurate geologic maps of the region. Based on the data acquired during the 1981-1982 austral summer, some earlier geologic maps can be revised. A total of 12 maps in the 1:250,000 Antarctic Geological Reconnaissance Series will be produced by combining this season data with information previously acquired.

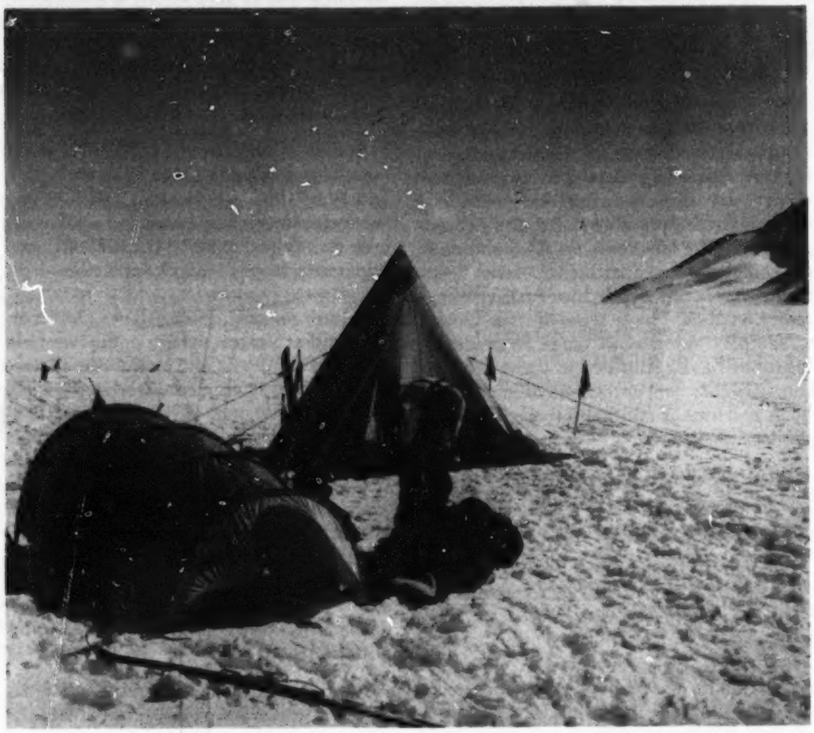
During the expedition each major rock group was investigated by at least one field party. Other investigations included studies of present and past glaciation, gravity and airborne-radiometric surveys, a meteorite search, and a biological investigation of lichens living beneath the surface of rocks. Reports on science projects conducted in northern Victoria Land will be published in the 1982 review issue of the *Antarctic Journal*.

The northern Victoria Land camp was one of several large field camps supported by the U. S. Antarctic Research Program in recent years. Other similar camps were in Marie Byrd Land (1977-1978), Darwin Glacier (1978-1979), and the Ellsworth Mountains (1979-1980). Of these, the northern Victoria Land camp supported the greatest number of science personnel and projects. In the Ellsworth Mountains 42 scientists participated in 7 projects, at Darwin Glacier 50 investigators took part in 12 projects, and in Marie Byrd Land 13 participated in 5 projects.

NSF photo by Russ Kinne.

In the Bowers Mountains (71°10'S 163°15'E) these geologists from Western Washington University are collecting granite cores with a diamond-bit coring drill, which is lubricated by a water-oil-alcohol mixture from the bottle in the foreground, as a part of a study of the region's tectonic history. They are interested in the region's position before the breakup of Gondwanaland.

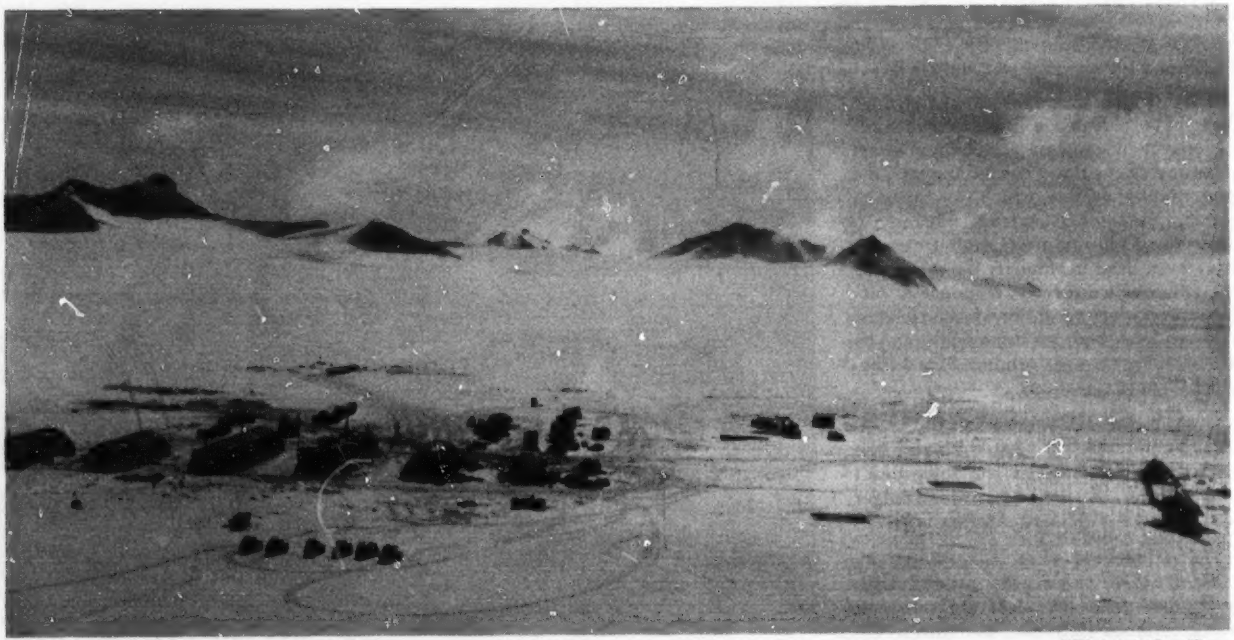
At Sledgers Glacier (71°26'S 162°48'E) in the Bowers Mountains a member of Antoni Wodzicki's (Western Washington University) party prepares the camp. The pyramid-shaped Scott tent, similar to tents used by Robert F. Scott, is stable in high winds and can be erected quickly. The dome-shaped, nylon Blanchard tent is another standard antarctic shelter.



NSF photo by Russ Kinne.

NSF photo by Russ Kinne.

Mason Hale, Smithsonian Institution, studies a sedimentary rock. Dr. Hale is a member of the biology team that came to northern Victoria Land to continue an investigation of algae, fungi, and bacteria living just beneath the surface of rocks.



NSF photo by Russ Kinne.

The northern Victoria Land base camp was established at the north end of Evans Névé near the head of the Canham Glacier (72°12'S 133°50'E). Like similar camps in prior years at the Darwin Glacier and Ellsworth Mountains, this one supported a large group of geologists, geophysicists, and glaciologist. The helicopter is one of three UH-1Ns used to transport field teams.

Newsletter 8
International Antarctic Glaciological Project Activities 1979-1981

The International Antarctic Glaciological Project (IAGP) is a study of a large part of the antarctic ice sheet, an effort involving Australia, France, Japan, the Soviet Union, the United Kingdom, and the United States. The coordinating council of the IAGP met on 18-21 October 1980 during XVI SCAR at Queenstown, New Zealand, and again on 14-15 September 1981 at Washington, D.C., after the Third International Symposium on Antarctic Glaciology at Columbus, Ohio, to review the activities and plans here summarized.

Australia. In addition to further movement, magnetic, and isotopic, surveys on Law Dome and in the upper reaches of the Totten and Vanderford Glaciers, a start has been made on a series of traverses, which ultimately are to extend along the 2,000-meter contour from Victoria Land in the east to the Sor Rondane Mountains and beyond into Queen Maud Land in the west. The first of these traverses from Casey Station has now reached longitude 123°E. An automatic weather station measured temperatures, 2 and 4 meters above the surface, and wind for 7 months at 68° 24′ 12° 10′E and will be reestablished after an overhaul. A second automatic station was to be established inland of Mawson Station in the 1981-1982 field season. An extended study of the growth and decay of sea ice near Mawson Station has been completed.

Further laboratory measurements of ice flow have revealed a linear relationship between the logarithms of minimum strain rates and of the times needed to reach the minimum strain rate, which was found to occur at the same strain for a wide range of stresses and temperatures. Computer models have been used to simulate the growth of the antarctic ice sheet in response to different boundary conditions (accumulation rate, sea level, bedrock depression) and the atmospheric changes produced by different ice sheet elevations.

Plans include an extension of the southern traverse toward Vostok Station, the drilling of holes upstream and downstream of a bedrock obstruction near Cape Folger, and the remeasurement of other holes on Law Dome.

France. Difficult sea ice conditions in 1979-1980 foiled the field program, but work resumed in 1980-1981 with a traverse to D59, 225 kilometers from the coast, where a 200-meter hole and several shallower ones were cored with a new electromechanical drill.

At Dome C (75°S 124°E) during the 1979-1980 field season a new probe was tested to locate the radioactive fallout layers from nuclear tests. Conductivity measurements were also performed in the field to investigate the possible input of volcanic dust over the last century. Also some of the samples stored after the 905-meter deep drilling were retrograded for further laboratory analysis. The analysis of these Dome C samples along with cores from other locations have continued to show significantly higher concentrations of microparticles and ions of continental origin during the last glaciation.

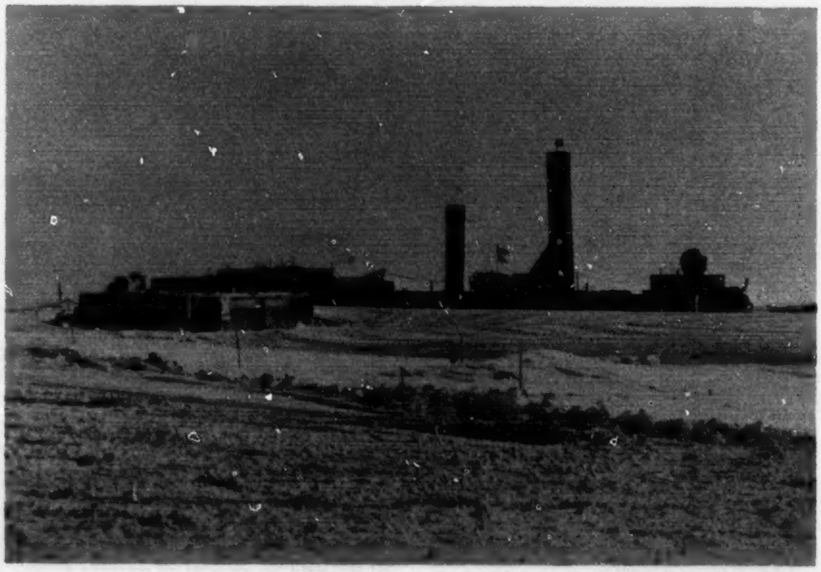
Plans include expanding logistics capabilities by adding a Twin Otter airplane to the facilities at Dumont d'Urville Station.

Japan. Glacial meteorology in the framework of POLEX-GARP (Polar Experiment—Global Atmospheric Research Program) has been carried out on the Mizuho Plateau where three ice cores varying in length from 130 to 143 meters were obtained. Aerial photographic surveys have covered the ice margins near Syowa Station and the Queen Fabiola and Sor Rondane Mountains. The analysis of previously obtained ice cores has continued.

Plans center on a new glaciological field program which will start in the 1980-81 field season with a traverse to the upper reaches of the Shirase Glacier and the establishment of a 120-kilometer trilateration network running inland from the southern end of the Queen Fabiola Mountains. Further intermediate drilling is planned at Mizuho Station.

Soviet Union. During further traverses from Pionerskaya to Dome C in 1979-1980 and 1980-1981, a new radar for sounding subsurface layers was tested and a 305-meter hole was drilled at 73° 14′ 110° 27′E, 665 kilometers from Pionerskaya. Other drilling projects produced new holes near Mirnyy (337 meters), Pionerskaya (360 meters), and at Vostok, where in the two field seasons a depth of 1,475 meters was attained. Features of this deep core were reported at the Third International Symposium on Antarctic Glaciology. Temperature and hole deformation measurements have been continued in the existing 900-meter holes at Vostok drilled in 1973 and in the 750-meter hole at Mirnyy drilled in 1979. Model studies have established characteristic time scales for thermal and dynamic processes in ice sheets and clarified the transition from predominant deformation flow to predominant sliding.

Plans include the continuation of the Dome C traverses, coring experiments in different fluids at Komsomolskaya, and snow surveys along all traverse routes and Soviet stations around the antarctic continent.



U. S. Navy photo (90227-12-78) by Douglas K. Nortell.

At Vostok, a Soviet Union station in East Antarctica, glaciologists drilled into the East Antarctic Ice Sheet, which is 3,360 meters thick at this location, to a depth of 1,475 meters between 1979 and 1981. The two towers (right center) house the drilling machinery.

United Kingdom. Work has continued on a comprehensive folio of observed physical characteristics of the antarctic ice sheet. The first 6 or 7 sheets were to be printed in February 1982, with the remainder to follow early in 1983. A detailed analysis of radar records has been made with special attention given to the as yet unexplained internal layers and the zone near the base of the glacier without these layers.

Plans include the development of a new sensitive radar system for layer studies and a growing involvement in the preparations of ERS I, a European satellite that will take over some of the ocean and ice tasks originally projected for the cancelled U.S. National Ocean Survey satellite.

United States. The 1979-1980 geophysical survey at Dome C included radar sounding, seismic shooting, geoelectric sounding, gravity and magnetic surveying, and magnetotelluric recording. In addition, a geoelectric survey and radar-sounding program was carried out with a geophysical team from the University of Munster, West Germany. This field work has been followed by intensive data analyses which are described in the 1980 (Volume 15, number 5) and 1981 (Volume 16, number 5) review issues of the *Antarctic Journal.*

Thirty-seven of the more than 450 overflights of East Antarctica by SEASAT satellite radar altimeter between 3 July and 10 October 1978 have been reduced and analyzed to produce detailed maps of the surface topography of the antarctic ice sheet. The study area extends from 120°E to 150°E and from the coast inland to 72°S.

U. S. Navy photo (90250-12-78) by Thomas E. McCabe, Jr.

Richard Tillson from the University of Nebraska's Polar Ice Coring Office packs ice cores, retrieved from the ice at Dome C, in special containers before shipping them to the United States.

A thorough analysis of 51 sections of the 905-meter Dome C core for the microparticle and oxygen isotope content indicates that a sharp increase in temperature occurred just at the end of the last glaciation. A summary report of the results of this analysis is reported in the 1980 review issue (Volume 15, number 5) of the *Antarctic Journal.*

Plans include further geophysical and strain measurements in 1981-82 field research on Dome C, and the core drilling at the South Pole.

Cooperative projects

Ongoing cooperative activities include geodetic and radar measurements by Australian glaciologists taking part in the Soviet traverse between Pionerskaya and Dome C, and French borehole studies coordinated with the Dome C geophysical survey. A new cooperative arrangement has been made by the French and Soviet expeditions for the intensive analysis of the 1,475-meter Vostok core. Consideration has been given to future collaboration in the 2,000-meter contour traverses in an international coring operation in ice more than 4 kilometers thick on the Casey-Vostok route. Time horizons there are well-spread along the vertical and annual layers could be detectable for 50,000 years.

The IAGP Council concluded the discussion with a recommendation for such a project and for deep drilling at other sites. Other resolutions were for a resumption of the English translation of the Information Bulletin of the Soviet Antarctic Expedition, for expanded studies of the glacial geology of peripheral ice-free regions of East Antarctica, and for maximum use of existing and forthcoming satellite data. The Council members held their next meeting in conjunction with the XVII SCAR meeting in Leningrad during June 1982.

For previous IAGP newsletters see the *Antarctic Journal* Volume IX, number 2, pages 42-46 and number 4, 187-189 (1974); Volume X, number 2, pages 51-55 and number 4, page 200 (1975); Volume 11, number 1, pages 36-37 (1976); Volume 13, numbers 1 & 2, pages 1-4 (1978); and Volume 15, number 3, pages 19-20 (1980).

—Uwe Radok, University of Colorado, Boulder, Colorado.

Glaciologists meet in Ohio

From 7 to 12 September 1981, 147 scientists from 11 countries gathered in Columbus, Ohio, for the Third International Symposium on Antarctic Glaciology. The international symposium, the first in 13 years devoted exclusively to antarctic glaciology, was sponsored by the Scientific Committee on Antarctic Research (SCAR), the International Commission on Snow and Ice of the International Council of Scientific Unions, and the International Glaciological Society. The National Science Foundation, through a grant (DPP 80-12877) to the Ohio State University, funded the meeting; the Institute of Polar Studies at Ohio State University hosted the meeting.

SCAR sponsored this symposium and the two previous ones through its working group on glaciology. The first, the Symposium on Antarctic Glaciology, was held in 1960 in Helsinki, Finland, and the second, the International Symposium on Antarctic Glaciological Exploration, in 1968 in Hanover, New Hampshire.

Conference organizers under the direction of the symposium chairman Colin Bull and the local chairman David Elliot assembled a scientific program with 76 papers presented at 8 sessions. These sessions focused on ice sheet stability, model studies, sea ice, ice shelves, glacial geology and history, the International Antarctic Glaciology Program, stratigraphic studies, and atmospheric and surface processes. An additional 21 papers were presented at three 90-minute poster sessions during which several papers were presented simultaneously at separate stations in an auditorium.

Under an agreement with the Council of the International Glaciological Committee 65 papers presented at the symposium and 40 other papers will be published in an upcoming volume of the *Annals of Glaciology.*

Fourth symposium on antarctic biology

Nutrient cycles and food chains will be the theme of the Fourth Symposium on Antarctic Biology to be held 12-16 September 1983 in Wilderness, South Africa. Arranged under the auspices of the Scientific Committee on Antarctic Research (SCAR), the symposium is cosponsored by the Scientific Committee on Oceanic Research and the International Association of Biological Oceanography. R. M. Laws, Director of the British Antarctic Survey, has been chosen as the chairman of the scientific steering committee and will be one of the conference proceeding editors.

The objective of the symposium is to bring together scientists working on nutrient cycles and food chains in terrestrial, marine, and freshwater antarctic and subantarctic ecosystems. Through papers and discussion participants will review existing knowledge and its application in major fields of research, pinpoint areas where more research is necessary, evaluate problems in each field, consider how multidisciplinary research might solve these problems, and identify priorities for future research.

The program will consist of invited and contributed papers. Scientists interested in contributing papers must submit a 200- to 300-word synopsis with a title to the Symposium Secretariat by 30 September 1982. The scientific steering committee will review proposed titles and synposes and notify the authors of the committee's decision by 31 December 1982. Manuscripts, not exceeding 15 pages including tables and illustrations, will be required by 31 July 1983. All papers will be sent to referees before they are accepted for publication in the printed proceedings. Authors, whose papers are accepted, should note that they must attend the conference and personally present their papers.

All correspondence related to the symposium should be directed to the Symposium Secretariat S.283, CSIR, P. O. Box 395, Pretoria 0001, South Africa. The international telephone number for the symposium office is +27 12 86-9211.

The three previous conferences held by SCAR dealt with microbiology, biogeography, ecology and physiology, and human physiology and psychology (1962, Paris, France); antarctic ecology and antarctic biology except human physiology and psychology (1968, Cambridge, England); and adaptations within antarctic ecosystems (1974, Washington, D.C.).

South polar skua at Palmer Station

The south polar skua (*Catharacta maccormicki*) is one of two skua species common to Palmer Station and the Anvers Island area. The bird's average weight is less than 1,800 grams, and its overall length is approximately 53 centimeters. It has a dark brown back with a black bill and feet that sometimes have white markings.

NSF photo by William Curtsinger.

A skua, like YABY, flies near the Antarctic Peninsula. "Many people thought YABY was a tame bird, a pet. But that's not so. YABY was as wild as all Antarctica. He was a lot like us, a migrant . . . . He was just better at it than we were . . . . He was hungrier, more aggressive, demanding, and, in the end, successful. His children will carry on for him." From Gary Bennett's eulogy for the south polar skua YABY. The eulogy was delivered in January 1982 at Palmer Station on Anvers Island.

With average wingspread of 127 centimeters this stocky bird is known for its rapid, powerful flight. It fiercely defends its territory, nest, and young and challenges intruders by raising its open wings over its back as it issues a harsh scream, known as a "long call." When defending its nest, it swoops down and strikes intruders with its wings and feet.

The south polar skua shares the Peninsula breeding grounds with the brown skua (*Catharacta lonnbergi*), which is a larger and more solitary bird. Both species are predators and scavengers, but studies conducted by University of Minnesota biologists since 1974 indicate that the south polar skua feeds mostly at sea and regularly brings its young krill and fish. It adapts to artificial feeding sites such as station dumps, and some of these birds prey on penguin eggs and young.

The south polar species is susceptible to climatic changes. In the Antarctic Peninsula region near Palmer Station the austral summers of 1974-1975 and 1975-1976, were relatively mild. During these two summers the south polar skua bred at record-high rates, and a larger than usual number of chicks survived. The next two austral summers, bad weather and severe ice conditions predominated. The combination of these two factors prevented the south polar skua from being able to get enough food for its young. In 1976-1977 skua productivity and chick survival rates dropped radically; in 1977-1978 no chicks survived.

Probably the most southern-ranging bird, the south polar skua has been sighted at many locations around the continent including the South Pole. It migrates northward into the subtropics and probably the northern hemisphere during the austral winter. Birds banded in the Antarctic Peninsula area have been recovered in Baja California, Mexico (September 1975) and Godthabsfjord, Greenland (July 1975). These and other recoveries have led biologists to believe that the south polar skua may regularly cross the Drake Passage and fly northward across the Equator into the North Pacific and North Atlantic regions.

During the week of 25 January 1982, the personnel of Palmer Station mourned the passing of a south polar skua named YABY, who was known to Palmer Station residents since he was banded in 1975. Each year he and his mate returned to their breeding ground on Bonaparte Point across from Palmer Station. Each year he faithfully defended his mate and young and struggled to survive in the icy antarctic environment. A notorious scavenger at the station, YABY claimed Palmer as his territory but was never tamed by his human companions.

YABY received his name when he was banded in 1975 by David Neilson. Mr. Neilson, who during that austral summer was a member of the University of Minnesota research team, has written the brief eulogy for YABY that follows.

Eulogy for YABY

Yellow, Aluminum, Blue, Yellow—YABY for short—the colorful band by which Palmer Station's resident skua was known. YABY bred across Hero Inlet from Palmer Station on Bonaparte Point since at least the 1974-75 austral summer. It was there on 15 January 1975 that I color coded YABY. From then on the legend grew.

YABY was a skua's skua. Despite his average size, breeding weight 1,300 grams, tarsus (leg) 68 millimeters and culmen (the edge of the bird's upper bill) 47.5 millimeters, he was unquestionably the dominant south polar skua in the area. No other south polar skua defended both a breeding and a feeding territory at Palmer except YABY. And what a prize feeding territory it was—the Palmer Station front porch! YABY had mastered the art of stealing Gary Bennett's delicious bratwursts and T-bones from a hot grill. Always the first in line, YABY made sure he brought home the bacon.

While YABY appeared tame at the station, he was really fearless and guarded faithfully his prize from all others. For YABY, it was a daily routine of long calls and wing raises until, being the last skua remaining, he would migrate north. Generally the first to return, YABY's migratory period at sea was the shortest of any south polar skua at Palmer—202 days. Defending Palmer meant being there.

On his breeding territory, YABY the protector was known only to a few of us who ventured there to band and weight chicks. What a rage he would assume when one stepped across the invisible, but real, territorial boundary. Catapulting off his perch while screaming the alarm call, he would swoop down upon us smartly administering head slaps with his leathery feet and talons. How many did we experience? Probably too many, perhaps not enough. It was just YABY's way of protecting his investment in the currency of life—the passing of genes to future generations. Without a doubt, YABY gave his all.

As the attentive parent, YABY and his mate YAWG bred each year, fledging six young between 1974-1975 and 1976-1977. Their successful reproduction was broken only by the icy 1977-1978 season when only six of over 200 skua pairs laid eight eggs. None were destined to hatch, but YABY and YAWG laid a full clutch of two and faithfully incubated them for 26 days until they finally aborted the cause after losing 20 percent of their body weight.

YABY's kids

Band number	*Date hatched*
877-34117	January 1975
877-34250	January 1975
877-36530	January 1976
877-36531	January 1976
877-36942	January 1977
877-37026	January 1977

The table lists the U.S. Fish and Wildlife Service band numbers for 6 of YABY's chicks and the month and year in which each chick was born. All of these chicks were banded by D. R. Neilson when he was a member of the University of Minnesota research team.

Can any skua succeed YABY at Palmer? In today's fickle world, his territorial devotion and faithfulness to YAWG seem unattainable, but there is hope. Certainly his superior genes have been perpetuated by his offspring, and maybe one of the kids (see table for list of chicks hatched and banded between 1975 and 1977) will return to Bonaparte Point and continue YABY's legend.

—David R. Neilson, Spooner, Wisconsin

Sailing directions for Antarctica revised

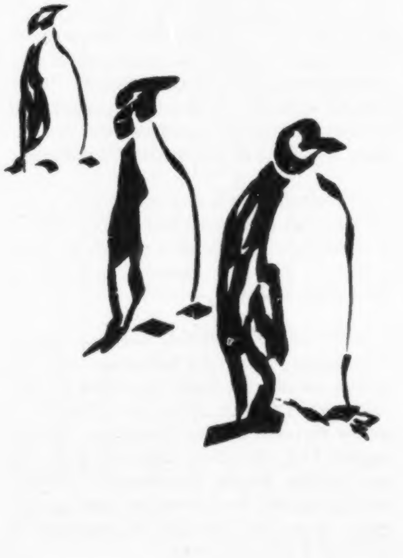
The Defense Mapping Agency Hydrographic and Topographic Center published corrected pages for *Sailing Directions for the Antarctic* (Publication 27—Change 1) in December 1981. These changes incorporate all revisions made since 1976 to the revised, second edition of the publication (1976) and include information from the British Admiralty *Antarctic Pilot*, 1974 edition.

The antarctic sailing directions describe the coasts of Antarctica and outlying islands as far north as 60°S latitude. Areas beyond the northern limit are included in other Defense Mapping Agency Hydrographic and Topographic Center sailing directions.

The second edition of the publication, issued in 1960, was compiled by RAdm. Robert A. J. English, U. S. Navy (Ret.) from various surveys and publications. Assistance was provided by staff members from the Johns Hopkins Medical School, University of Michigan, Library of Congress, Department of State, National Archives, American Museum of Natural History, Smithsonian Institution, the Royal Geographic Society (London), and the Hydrographic Department of British Admiralty.

The Defense Mapping Agency publishes the sailing directions under the authority of a Department of Defense directive and sections *Titles 10 and 14* of the U. S. Code. They comprise information on harbors, coasts, and waters around the world that cannot be illustrated on nautical charts or that is not available from other sources. Although new editions are issued only at specific intervals, changes made between updates are published in the weekly Notice to Mariners.

Purchasers of the book receive published changes free of charge. Subsequent changes may be purchased from sales agents listed in the DMA brochure *Numerical Listing of Charts and Publications* (Pub. 1-N-L) or ordered by mail directly from the Defense Mapping Agency, Hydrographic/Topographic Center, Attention: DDCP, 6500 Brookes Lane, Washington, D.C. 20315. The price of the book is $4.50. Orders must be accompanied by a check from a U.S. bank or a money order. Both should be made payable to the Defense Mapping Agency. U. S. naval vessels and government agencies, which require copies for official use, will receive future changes automatically. If a government agency needs copies for its programs, the agency can request to be added to the official distribution list by contacting the Defense Mapping Agency at the above address.



Special requirements for Greenland research

All U.S. scientific research projects in Greenland must be approved in advance by the Danish government. Applications for projects in Greenland in which Americans are involved in any way are submitted to the Danish government by the U.S. Department of State.

Project Proposal/Data Sheet for U.S. Scientific Research in Greenland

An application to conduct research in Greenland must be completed on the "Project Proposal/Data Sheet", a Danish form available from sponsoring U.S. agencies.

A separate application form must be prepared for each project. This includes continuation projects from previous years, subprojects of larger projects, and on-site preparatory investigations and surveys. If formal cooperation with Danish scientists during the field work for the project is planned, this cooperation should be fully arranged before the data sheet is submitted.

Data sheets must be submitted to the sponsoring U.S. agency, which then collects and forwards them to the U.S. Department of State. The Department of State sends the Data Sheets to the Danish Ministry of Foreign Affairs. U.S. agencies are required to present the proposed projects formally for consideration by the Danish Commission for Scientific Research in Greenland, at a meeting held in Copenhagen each spring.

No project may begin before the Danish government has officially approved it. Although the Danish Scientific Commission may approve the scientific content and scope of a project, this does not automatically insure final approval of the project by the Danish government. Other Danish agencies involved in the approval process may refuse permission for operational, logistical, or environmental reasons.

This procedure is not new, but it is important for U.S. scientists to provide to their sponsoring agencies as much advance notice as possible concerning planned Greenland research.

Scientists contemplating National Science Foundation support for Greenland research should contact the Polar Coordination and Information Section, Division of Polar Programs, National Science Foundation, Washington, D.C. 20550 for application forms and further details. Information on projects proposed for Greenland during calendar year 1983 should be provided to NSF by 1 October 1982.

Foundation awards of funds for antarctic projects, 1 October to 31 December 1981

Following is a list of National Science Foundation antarctic awards made from 1 October to 31 December 1981. Each item contains the name of the principal investigator or project manager, his or her institution, a shortened title of the project, the award number, and the amount awarded. If an investigator received a joint award from more than one Foundation program, the antarctic program funds are listed first, and the total amount of the award is listed in parentheses. Awards initiated by the Division of Polar Programs contain prefix DPP in the award number, those by the Division of Atmospheric Sciences, ATM, and those by the Division of Environmental Biology, DEB.

Glaciology

Bentley, C. R. University of Wisconsin, Madison, Wisconsin. Geophysical investigation of the Dome C area, Antarctica. DPP 78-20953. $162,032.

Stuiver, Minze. University of Washington, Seattle, Washington. Eleventh International Radiocarbon Conference. ATM 81-07137. $6,000. ($24,000).

Biological and medical sciences

Cairns, Stewart D. Smithsonian Institution, Washington, D.C. Systematic analysis of the Stylasterina. DEB 81-02776. $5,000 ($24,573).

Landrum, Betty J. Smithsonian Institution, Washington, D.C. Cooperative systematics and analyses of polar biological materials. DPP 79-20835. $99,695.

Earth sciences

Dalziel, Ian W. Columbia University, Palisades, New York. Penrose Conference: The Antarctic Plate - A Global Perspective. DPP 81-15101. $9,200. ($13,200).

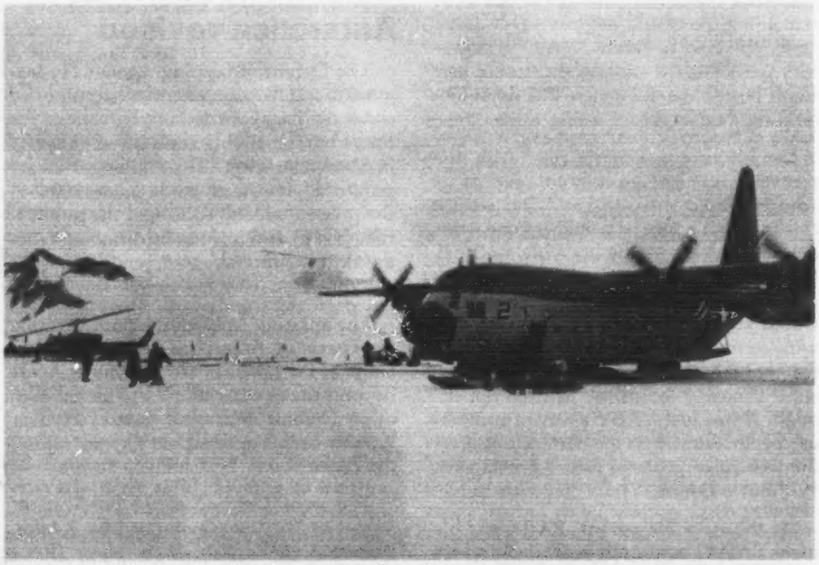
Dalziel, Ian W. Columbia University, Palisades, New York. Evolution of the West Antarctic-Andean-Cordillera in the Scotia Arc Region. DPP 78-20629. $64,959.

Ernst, Wallace G. University of California, Los Angeles, California. Petrology of Precambrian crystaline rocks. DPP 80-19527. $45,000.

Evans, John C. Battelle Memorial Institution, Richland, Washington. Terrestrial ages of Antarctic meteorites using ^{26}Al and ^{53}MN techniques. DPP 80-20908. $47,982.

Ford, Arthur B. U.S. Geological Survey, Reston, Virginia. Geology and petrology of the Dufek Intrusion. DPP 80-20753. $35,000.

(Continued on back cover.)



NSF photo by Russ Kinne.

An LC-130 airplane and two UH-1N helicopters near the main northern Victoria Land camp. Construction material, personnel, fuel and supplies were transported between McMurdo Station and the camp by 68 LC-130 flights. UH-1N helicopters flew 533 hours in support of science projects, second only to the Darwin Glacier expedition when 617 hours were flown.

Weather at U.S. stations

Feature	NOVEMBER 1981				DECEMBER 1981				JANUARY 1982			
	McMurdo	Palmer	Siple*	South Pole	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole
Average temperature (°C)	-11.2	-2.4		-41.6	-3.4	-0.8	-12.8	-28.3	-3.7	-0.2	-11.9	-29.1
Temperature maximum (°C) (date)	0.0 (19)	5 (27)		-32.9 (12)	-2.8 (13)	6.0 (17)	4.0 (24)	-19.9 (30)	-4.1 (9)	7.1 (28)	5.7 (5)	-20.7 (3)
Temperature minimum (°C) (date)	-21.7 (6)	-18 (18)		-53.4 (1)	-10.6 (11)	-8.5 (29)	-25.0 (4)	-36.6 (1)	-12.8 (29)	-7.6 (5)	-20.1 (20)	-35.9 (25)
Average station pressure (mb)	987.5	978.5		676.9	981.7	984.7	858.9	681.5	991.4	989.2	867.2	689.8
Pressure maximum (mb) (date)	1010.5 (18)	1002.0 (30)		686.3 (26)	991.4 (17,18)	999.2 (14)	868.9 (31)	690.6 (29)	1005.3 (19)	1006.8 (25)	876.1 (24,25)	696.9 (19)
Pressure minimum (mb) (date)	959.0 (7)	963.0 (23)		663.8 (4)	967.2 (13)	967.4 (13)	846.8 (9)	670.1 (3)	982.2 (10)	970.8 (17)	858.1 (31)	676.6 (27)
Snowfall (mm)	78.4	55.9		Trace	17.8	55.9	Trace	Trace	160.0	---	177.8	Trace
Prevailing wind direction	090°	020°		045°	010°	330°	150°	045°	090°	340°	210°	045°
Average wind (m/sec)	4.2	6.7		3.9	4.2	4.2	3.8	3.3	2.9	3.4	4.1	3.7
Fastest wind (m/sec) (date)	8.9 (29) 180°	31.3 --- 360°		15.9 (11) 360°	10.3 (30) 170°	23.2 (10) 360°	17.4 (31) 250°	12.3 (3) 315°	9.8 (16) 180°	33.9 --- 060°	15.6 (18) 140°	11.8 (3) 360°
Average sky cover	5.6	8/10		5.3	6.1	9/10	6.1	6.4	7.3	8.4/10	7.1	6.1
Number clear days	2	2		15	0	0	2.7	8	0	0.4	4.4	12
Number partly cloudy days	10	9		5	9	13	6.8	8	5	12.7	5	4
Number cloudy days	18	19		10	22	17	22.5	15	26	17.9	20.7	14
Number days with visibility less than 0.4 km.	0.06	---		2	0	---	1.7	2	0	---	4.8	1

Prepared from information received by teletype from the stations. Locations: McMurdo 77°51'S 166°40'E, Palmer 64°46'S 64°3'W, Siple 75°55'S 83°55'W, Amundsen-Scott South Pole 90°S. Elevations: McMurdo sea level, Palmer sea level, Siple 1054 meters, Amundsen-Scott South Pole 2835 meters. For prior data and daily logs, contact National Climate Center, Asheville, North Carolina 28801.

*Station not operating.

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(*Continued on page 14.*)

Support and services

Costello, John D. Department of Transportation, Washington, D.C. U.S. Coast Guard icebreaker support, 1981-1982. DPP 80-24892. $1,450,000.

DeVore, George W. Florida State University, Tallahassee, Florida. Curatorship of core collections. DPP 75-19723. $128,943.

Gray, Rodney E. ITT Antarctic Services, Inc., Paramus, New Jersey. Antarctic Support Services. DPP 80-03801. $3,500,000.

Kinne, Russ. Russ Kinne Inc., New Canaan, Connecticut. Photographic documentation. DPP 82-01434. $14,202.

Landrum, Betty J. Smithsonian Institution, Washington, D.C. Recording of data and sorting of collections from polar regions. DPP 74-13988. $87,598. ($129,300).

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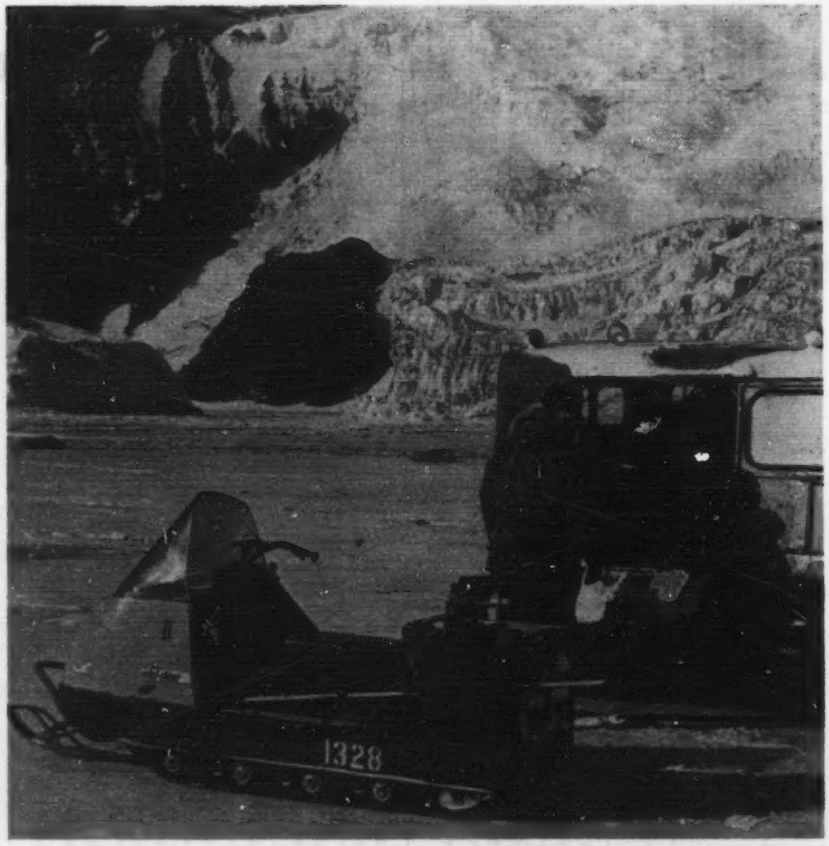

U. S. Navy photo (XAM-0514-A-12-80) by Paul M. Del Signore.

At Turks Head near McMurdo Station biologists from the University of Minnesota prepare equipment before beginning to tag and weigh Weddell seals. The seals sleep on the sea ice in the background.

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antarctic journal OF THE UNITED STATES

June/September 1982 National Science Foundation Volume XVII—Numbers 2 & 3

U. S. antarctic research, 1982-1983

NSF photo by William Curtsinger.

The Antarctic Peninsula, seen in this photograph from the deck of the R/V Hero, will be the site of 11 biology projects during the 1982-1983 austral summer. The biological richness of this region has drawn U. S. scientists to investigate both individual organisms and antarctic marine and terrestrial ecosystems for the last two decades. To conduct these investigations, biologists will use Palmer Station and the R/V Hero, which will make three research cruises along the Peninsula between November 1982 and March 1983.

During the 1982-1983 austral summer approximately 270 investigators from U.S. universities and research institutes will conduct 88 antarctic science projects, sponsored by the National Science Foundation (NSF) and U. S. government agencies as a part of the U.S. Antarctic Research Program. The projects will be conducted at four U. S. year-round stations, with the antarctic programs of four other countries, in remote areas of the continent, and aboard NSF's research ship *Hero* and the U. S. Coast Guard icebreakers *Glacier* and *Polar Star*. The goals of the U. S. Antarctic Research Program—to expand fundamental understanding of the continent and to study its relationship to global problems—are reflected in the diversity of this year's field program. Research projects are balanced among the disciplines of marine and terrestrial biology, atmospheric sciences, ocean sciences, glaciology, and earth sciences.

Biology

Understanding the structure and functioning of the antarctic marine ecosystem has been an important research objective over the last two decades. Growing commercial catches of krill and the 1982 entry into force of the Convention on the Conservation of Antarctic Marine Living Resources have pointed to the need to learn more about marine flora and fauna and their ecological relationships. This year's biological research at Palmer and McMurdo Stations and aboard the two icebreakers and *Hero* will augment the body of scientific information about the marine ecosystem.

The variety of life around Palmer Station, near the Antarctic Peninsula, enables scientists to study the physiology and habitats of organisms along with interactions at all levels of the ecosystem. Research concerning krill will include continued investigations of how water temperature and pressure influence development, what environmental factors influence swarming behavior, what physiological factors affect the early survivorship of krill larva, and what seasonal and areal differences contribute to egg production. Other projects will focus on food web relationships, the behavioral and ecological relationships among three species of penguins, and benthic invertebrate ecology. Investigations of how zooplankton, fish, penguins, and sea birds adapt to low temperatures and other aspects of the antarctic environment will be continued.

Marine biology at McMurdo Station and in the waters surrounding the continent complements the research to be conducted in the Peninsula region. Focusing on the microbial level, one group of biologists will study the algal and bacterial communities that develop on the underside of sea ice where low light limits photosynthesis even during summer. When the sea ice melts, many of these physiologically active microorganisms are released and provide a basis for subsequent plankton blooms of tiny plants.

Low-temperature adaptation of cod and other antarctic fish will be investigated by two groups of biologists. Over several years biologists have isolated from the blood of these fish a glycoprotein antifreeze that

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lowers the freezing point of fluids in these fish and enables them to survive in cold waters. By continuing their investigations, they hope to determine the distribution of these compounds and to understand how their molecular structures relate to their functions.

Medical researchers will probe how pregnant Weddell seals communicate the onset of a breath-hold dive to their unborn young. Laboratory studies of these seals, which can stay under water longer than any other marine mammal, have shown that the fetal heart rate slows before any changes in blood gas composition can be communicated from the mother. By recording fetal and maternal heart rates and seawater pressure during dives, the biologists hope to discover what triggers the fetal diving response.

Editor: Winifred Reuning

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The Director of the National Science Foundation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this agency. Use of funds for printing this periodical has been approved by the director of the Office of Management and Budget through 31 March 1984.

Learning more about marine mammal and bird distribution around the continent will help scientists to better understand the marine ecosystem. From aboard the U. S. Coast Guard icebreaker *Polar Star*, which will make a circumantarctic cruise this austral summer, biologists will gather data on bird distribution, a preliminary view of microbial and plankton communities along the ice edge, an assessment of marine geochemistry of surface waters, and the types of marine birds and mammals populating the pack ice.

Biologists interested in terrestrial ecosystems will conduct research near McMurdo Station and in the Peninsula region. Two projects in southern Victoria Land will be continued. One focuses on the physiological adaptations of algae in freshwater lakes, while the other concentrates on lichen and bacteria living just below the surface of rocks.

In a new project biologists will study plant communities of the Antarctic Peninsula. Because the harsh environment causes these plants to emphasize stress tolerance over diversity, vegetation is sparse, unevenly distributed, and well adapted to local climate. Short summers, shallow depth of thaw, cold dry winds, and water shortages combine to limit the abundance of plants. By collecting data on different plant communities, soil types, and environmental factors, biologists will get information that can be used to measure changes brought about by human activity.

Upper atmosphere studies

Extended observations of the sun from Amundsen-Scott South Pole Station have provided new insight into the structure and dynamics of the solar interior. Two solar telescopes near South Pole Station will be operated this season. U. S. and French scientists will use one telescope, which was installed 2 years ago, to study supergranules (1,500-kilometer-wide solar features caused by the movement of gas in the solar convection zone), solar convection and cycles, and surface temperature distribution. The second telescope, tested during the 1980-1981 austral summer, is a portable, 4.6-meter-long tube with a 30.5-centimeter diameter and a 10.4-meter focal length. With this telescope astronomers will observe brightness oscillations, which can be related to natural solar resonances. Their measurements of longer period oscillations will help characterize the sun's deep interior.

Personnel from four projects will install and test a prototype automatic unmanned geophysical station near South Pole Station. Measurements taken by such stations are useful for constructing comprehensive models of interactions among the solar wind, the magnetosphere, and the ionosphere. The station includes a digital micropulsation instrument that measures changes in magnetospheric wave frequencies and amplitudes and a riometer (relative ionospheric opacity meter) that provides data on temporal and spatial variations of energetic particle precipitation from the magnetosphere. The station will begin year-round operation in December 1982.

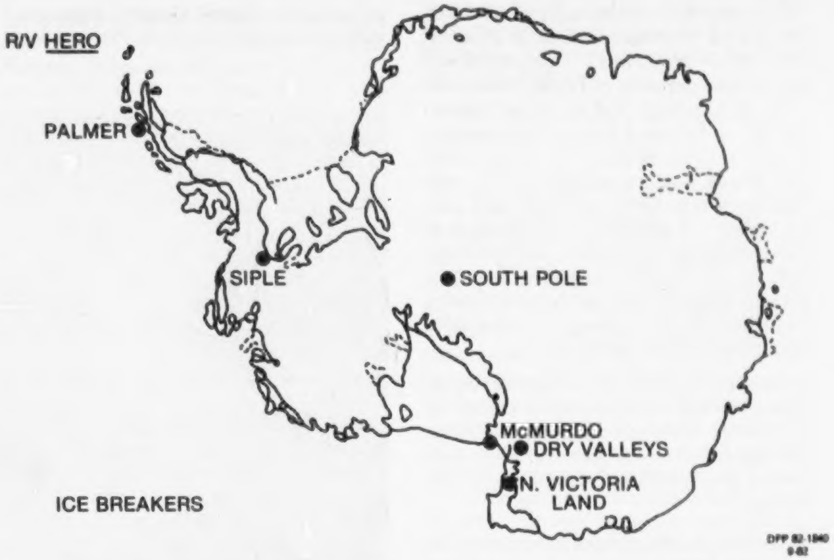
Other upper atmosphere research at the South Pole includes continued monitoring of auroras to improve understanding of the Earth's magnetospheric processes. Researchers will probe interplantary space by observing and monitoring cosmic rays and investigate disturbances produced by electron-density irregularities in the atmosphere 70 to 80 kilometers above the Earth.

At Siple Station several projects will focus on processes and interactions in the upper regions of the Earth's atmosphere. Siple Station is located at one end of a geomagnetic line of force that passes outward through the plasmapause and returns to Earth at a northern conjugate point in eastern Canada. Scientists send waves from Siple Station at radio frequencies through the plasmapause and record them in the northern and southern hemisphere. This enables them to study the response of the magnetosphere, which begins 100 kilometers above the Earth and extends outward into space, to known perturbations. The experiments this austral summer will be conducted in conjunction with four satellites orbiting over the polar regions and coordinated with research at the South Pole and Palmer Stations and the British station Halley on the Weddell Sea.

Meteorology

Antarctica is a well-defined climatic region, characterized by severe low temperatures, relatively low precipitation, and a permanent ice sheet. Numerical models of meteorological processes suggest that the continent and its environment to some extent magnify observable changes in global climate. Without local or regional pollution sources the environment at South Pole Station is ideal for monitoring and investigating the chemistry of the Earth's atmosphere and the climatic impact of such atmospheric trace gases as fluorocarbons, carbon dioxide, and ozone. This year meteorologists will continue to monitor air chemistry at South Pole Station. Data will also be gathered along the coast at McMurdo and Palmer Stations and from LC-130 airplanes over the continent and enroute from the United States. Information on the lifetime and circulation patterns of these gases will be added to existing data, acquired at other stations around the world, and will be useful for refining models to predict the long-term effects of these gases on global climate.

U.S. ANTARCTIC RESEARCH PROGRAM
1982-1983
LOCATIONS OF MAJOR ACTIVITIES



Regional weather patterns bring pollutants to the continent, transport energy and water to and from Antarctica, and influence the mass of snow and ice on the continent and at sea. To understand how these patterns relate to weather in other parts of the world, meteorologists are probing unique features of the antarctic climate. For several years researchers have been gathering data on katabatic winds, cold heavy air draining from the polar plateau down to the coast under the force of gravity. Three automatic weather stations placed between Dome C (1,000 kilometers inland) and the French station Dumont d'Urville on the coast collect data on wind speed and direction, temperature, and dew point.

Other automatic weather stations around McMurdo Station and at Dome C and Byrd and Siple Stations will provide meteorologists with surface data transmitted by means of polar-orbiting satellites. This year four stations will be installed in the Weddell Sea region by the British Antarctic Survey for U. S. investigators. Scientists will collect data on barrier and foehn winds, terrain effects, and ice transport in this region, where little is known about local weather.

To learn more about seasonal weather patterns in Antarctica, a group of meteorologists will test prototype air samplers at South Pole Station and from LC-130 airplanes. Past research indicates that the chemical composition of aerosols differs from winter to summer and suggests that distinct seasonal circulation patterns exist. The system, to be tested this season, enables researchers to trace the seasonality of aerosols and relate this to weather patterns. A methane tracer will be released into the katabatic flow at the South Pole Station. To follow the tracer's passage to the continent's periphery scientists will collect air samples at coastal locations near McMurdo and Palmer Stations and at Siple Station.

Ocean sciences

Fluctuations in the extent of antarctic ice shelves may control the size of the West Antarctic ice sheet, which in turn would change world sea-level. Past investigations suggest that melting at the base of these ice shelves is a significant factor in their stability and that melting is controlled by oceanic heat from the open ocean. In October oceanographers will begin to monitor the heat flux to the area beneath the Ross Ice Shelf, a roughly 400-meter thick sheet of floating ice over 500,000 square kilometers in area. The researchers will measure salinity and temperature at 26 locations in the Ross Sea to determine geostrophic currents generated by horizontal density differences and the earth's rotation. Some direct current measurements will be made at the face of the Ross Ice Shelf. Another focal point in the investigation will be the Erebus Glacier Tongue, a 16-kilometer-long ice intrusion from the Erebus Glacier into the Ross Sea. Oceanographers will examine what effect melting from the ice tongue has on the salt and heat structure of the adjacent water.

Sediment coring will continue along the antarctic continental margin. From aboard the icebreaker *Glacier* marine geologists will collect samples of ancient sediments, survey iceberg sediment transport, and conduct closely spaced bottom sampling of benthic foraminifera in the Ross Sea. Data from the continental margin survey will contribute to the construction of detailed bathymetric maps and will be useful in plotting ice fronts. In another continuing project researchers will gather data on the extent of marine-based ice sheets during the last glacial maximum between 17,000 and 21,000 years ago.

Glaciology

Near South Pole Station glaciologists will take a 500-meter ice core. Besides returning the core to the United States for distribution, glaciologists on site will evaluate samples for information on past climates. Using techniques developed for research in Greenland, investigators will analyze the air bubbles frozen in the core for carbon dioxide content. They are particularly interested in learning if the carbon-dioxide content of the air in the past is related to glaciation.

The 500-meter core should provide a record of the last 6,200 years, encompassing three periods of documented mountain glacier expansion. Another group of glaciologists will use this extensive climatic record to examine fluctuations in atmospheric concentrations of insoluble particles. They believe that a relationship may exist among snow accumulation rates, increased concentrations of insoluble particles, and lowered temperatures.

Earth sciences

Geologists will concentrate their investigations this year in northern and southern Victoria Land. Two groups will return to northern Victoria Land to expand research conducted last year in the region. Two other groups will travel aboard the *Glacier* to Mt. Melbourne (74°21'S 164° 42'E), a 2,730-meter volcano between Wood and Terra Nova Bays. In addition to mapping 160-million-year-old volcanic rocks, they will collect samples for comparison with similar rocks from the Mt. Erebus region and Marie Byrd Land. Their research focuses on the volcanic and glacial history recorded in the samples and on assessing the composition of the Earth's mantle in the Ross Sea area.

In southern Victoria Land at Szabo Bluff (86°29'S 144°48'W) two teams will conduct resource-related surveys. Continuing research that has been conducted in the Ellsworth Mountains, northern Victoria Land, and the ice-free valleys of southern Victoria Land, geologists will use gamma-ray spectrometry to locate radioactive outcrops near Szabo Bluff. Using samples taken at these outcrops, another geologist will identify the minerals present to learn more about the physical and chemical conditions under which the minerals were positioned.

Several projects will be based in the ice-free (dry) valleys of southern Victoria Land. In conjunction with New Zealand scientists U. S. geologists will drill eight 40- to 60-meter deep rock cores in eastern Taylor Valley to gather more data about the glacial history of the valley and the Ross Sea. Stratigraphic, paleomagnetic, and sedimentologic investigations will be conducted. Another group of U. S. geologists will map glacial deposits in Taylor Valley and also in Marshall Valley, Quartermain Range, and Asgard Range. Geologists in one project will address in detail the nature and rate of ongoing physical and chemical processes in Victoria, Wright, and Taylor Valleys. In addition to contributing to the general understanding of how these valleys were formed, data from this project over several years will help to identify how the valleys are changing and predict how they may be evolving.

Continuing projects in the McMurdo region include seismic gravity studies of the Earth's crust and upper mantle along the boundary between East and West Antarctica and seismic observations of Mt. Erebus.

Geologists will search for meteorites in southern Victoria Land and in the Thiel Mountains near the Weddell Sea. Mapping operations will be carried out by the U. S. Geological Survey in southern Victoria Land and along the Siple Coast. Geological Survey personnel will also conduct geodetic surveys in northern Victoria Land and gather data for the Worldwide Standardized Seismological Network at South Pole Station.

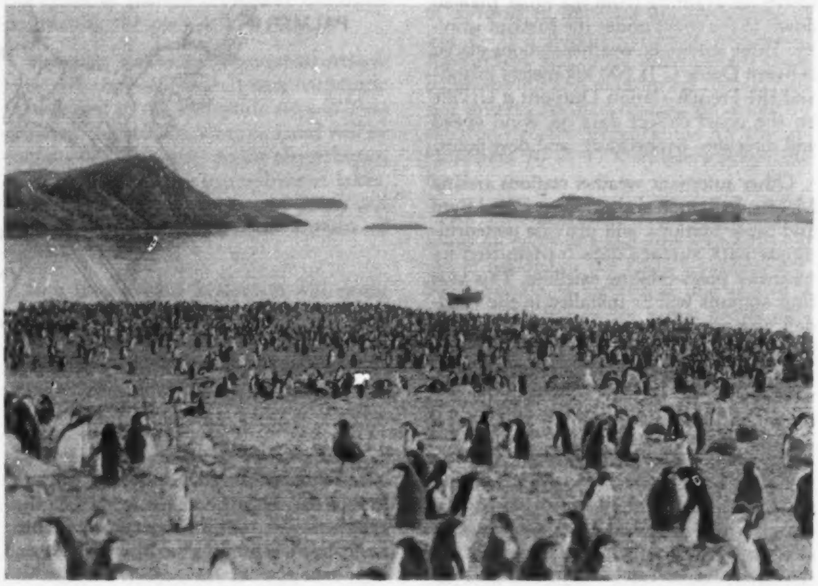
Support

The Foundation's research ship *Hero* and the U. S. Coast Guard icebreakers *Glacier* and *Polar Star* will support marine research between November 1982 and March 1983. The *Hero* will make three cruises between Palmer Station and Punta Arenas, Chile, and will support research near Palmer Station and along the Antarctic Peninsula. The *Polar Star* will make a circumantarctic cruise this season, while the *Glacier* will concentrate on science support between New Zealand and McMurdo Station and in the Ross Sea.

Besides its circumantarctic cruise and science support, the *Polar Star* will resupply Palmer Station in November and will stop at the station again in March to pick up passengers and cargo for return to the United States. In January 1982 the *Polar Star* will open a channel in McMurdo Sound ice for the resupply ship USNS *Southern Cross* and the fuel tanker *Maumee*.

In addition to flying LC-130 airplanes and UH-1N helicopters, U. S. Navy personnel of the Naval Support Force Antarctica and the Antarctic Development Squadron Six will maintain communications, weather forecasting, air traffic control, and other services at McMurdo Station and at other locations on the continent. A contractor, Antarctic Services Inc. (a subsidiary of Federal Electric Corporation), will operate and maintain Palmer, Siple, and Amundsen-Scott South Pole Stations and the R/V *Hero*. At McMurdo Station, the contractor will perform construction and support functions and operate the scientific laboratories and Williams Field, McMurdo's ice-shelf skiway.

On the following pages, brief descriptions of projects of the 1982-83 austral summer and the 1983 winter are provided.



NSF photo.

In a small boat slightly offshore, a scientist observes an Adélie penguin rookery on Anvers Island, near the Antarctic Peninsula. A skua, a predator of these birds, is in the foreground among the penguins. During this austral summer biologists will continue to investigate how Adélie penguins regulate their body heat in order to survive the harsh climate.

Planned field research projects, 1982-1983

Antarctic Peninsula

Growth and metabolism of marine crustacea in relation to temperature and pressure. *Robert Y. George, University of North Carolina at Wilmington.* At Palmer Station during the 1981-1982 austral summer, we studied how temperature influences metabolic responses of krill at different stages of development and what impact pressure and temperature have on krill embryology. This austral summer, we will participate in two R/V *Hero* cruises to continue this reseach. Our objectives are to understand the relationship of temperature to krill swarming behavior, the role of increased pressure on krill egg development, and the genetic variations in adult and larval krill from different geographic locations. We will also compare metabolic and growth strategies in cold-adapted euphasiids, isopods, and amphipods to similar temperate crustaceans. (S-001)

Antarctic krill (Euphausia superba) behavior. *William M. Hamner, University of California.* Our 2-year study on the behavior of krill in swarms has broad implications at all levels of the antarctic food chain. At sea, divers will operate an underwater vehicle to locate krill and describe density, orientation, and size of krill within swarms. Krill will be captured from selected swarms with handheld, monofilament underwater nets and small trawls. Laboratory studies of behavioral responses and structural morphology will be conducted at Palmer Station. This season we also will track Adélie penguins and blue-eyed shags from rookeries near the station to their feeding grounds and analyze the feeding habits of sea-bird predators of krill. (S-006)

Thermoregulatory mechanisms in Adélie penguins. *David E. Murrish, State University of New York.* We will continue to study thermoregulation of Adélie penguins. The penguins will be captured in the Antarctic Peninsula area for laboratory and field experiments on the modulation of heat loss through brood patches, feet, and flippers (wings). (S-011)

Egg production and factors affecting early larval survivorship in krill (Euphausia superba). *Robin M. Ross, University of California.* Working near the South Shetland Islands (primarily in the Bellingshausen Sea and the Bransfield Strait), we will sample and observe spawning krill (*Euphausia superba*) to determine the seasonal and areal variation in daily egg production. During our cruise we will collect temperature-depth profiles with expendable bathythermographs and salinity-depth data. An *in vivo* chlorophyll fluorescence monitor will be used on pumped surface water throughout the cruise. At three locations chlorophyll *a* and particulate lipids will be sampled at different depths near selected krill swarms. Our research will be conducted throughout the austral summer so that we may begin to answer some basic questions about the length of the spawning season and the potential change in brood frequency. Other objectives are to determine the geographic distribution of krill swarms and the length, frequency, sex ratio, and maturity stages of individuals in each swarm and to investigate any seasonal or locational differences that may exist in egg production rates. We also hope to identify the physiological factors affecting early larval survivorship and the best areas for spawning. (S-014)

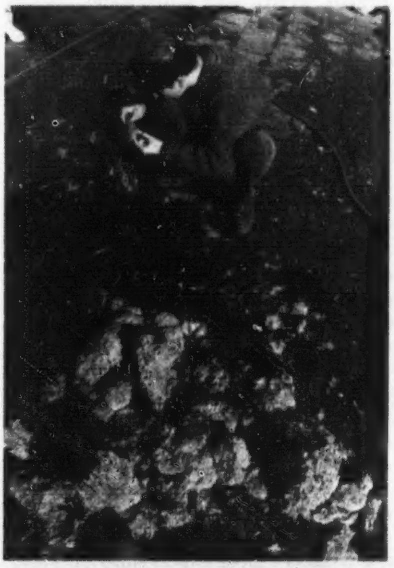
Trophodynamics of the mesopelagic fauna in the southern Drake Passage. *Thomas Hopkins, University of South Florida.* Mesopelagic micronekton, mainly fish and crustacean species, comprise a significant component of the antarctic marine food web and probably are important predators of krill and other zooplankton. This austral summer we will continue to investigate the feeding and nutrient flux patterns of these fish and crustaceans in the Drake Passage, north and west of Anvers Island. Discrete depth samples of micronekton and zooplankton will be collected with an opening-closing midwater trawl at depths between the surface and 1,500 meters, with additional open-net hauls made near krill swarms. We will sort, identify, and count subsamples of zooplankton and micronekton and determine size-dry weight relationships for dominant species. For dominant fish species and, where possible, for dominant crustacean species, we will examine stomach and intestinal contents to determine their diets. Zooplankton, micronekton, and the stomach contents of micronekton will be analyzed for caloric and nutritional value. Data analysis will provide us with a picture of the abundance and distribution of micronekton and their prey, the feeding strategies of principal fish species, and the energy and nutrient flow between micronekton and their prey. (S-020)

Southern ocean ecosystems study. *Bruce H. Robison, University of California, Santa Barbara.* In conjunction with the University of South Florida research team (see S-020) we will investigate feeding and nutrition patterns of micronektons, primarily fishes and crustaceans, and attempt to assess the principal components of mesopelagic micronekton and zooplankton communities. From aboard the R/V *Hero* we will do midwater trawling in the Bransfield Sea-Drake Passage region and in the Bransfield Strait near Palmer Station. To obtain estimates of microzooplankton abundance 30-liter bottle collections will be made at several depths between the surface and 1,000 meters. Although the University of South Florida investigator will conduct some preliminary analysis while aboard the *Hero*, most of the analysis will be accomplished at shore-based laboratories. (S-023)

Ecological relationships, zoogeography, and systematics of helminth parasites infecting sea birds. *Robert L. Rausch, University of Washington.* No records for parasites from the Palmer Archipelago have been made, and no comprehensive studies of parasites of related species of antarctic sea birds exist. We will attempt to acquire these data and provide a basis for comparing ecosystem studies of parasites of arctic colonial nesting sea birds, as well as increase scientific understanding of the dynamics of parasitism among nesting birds in isolated colonies. For this project we will take birds from colony sites near Palmer Station on Anvers Island, on the islands in Arthur Harbor, along the Antarctic Peninsula, and at sea. Emphasis will be placed on characterizing parasites of different species of sea birds, which colonize the same location but do not interbreed. These species will be divided into ecological groups based on differences in their feeding habits. (S-027)

Adaptations in protein metabolism. *Audrey E.V. Haschemeyer, Hunter College.* Our project focuses on the regulation of protein metabolism in antarctic marine organisms that live at extremely low temperatures year-round. Working out of Palmer Station, we will collect live fish to evaluate synthetic demands for metabolism, growth, and reproduction. The changing patterns of liver protein synthesis, particularly antifreeze glycoprotein and egg proteins, in antarctic fish will be compared to seasonal and reproductive stages. This year's research focuses on protein synthetic activity in liver and erythropoietic tissues of nototheniid fish and hemoglobin-free ice fish *Chaenocephalus aceratus*. Temperature-sensitive factors will be identified by comparative analysis of protein synthesis in cells from antarctic and temperate fish. The results should provide insight into the regulation of protein synthesis in lower vertebrates and the evolution of this fundamental biological process that allows organisms to adapt to extreme environments. (S-032)

Plant communities near Palmer Station, Antarctic Peninsula. *Vera Komarkova, University of Colorado, Boulder.* In an area of high environmental stress such as the Antarctic, plant types decrease in diversity, and plant communities are organized simply with an emphasis on stress tolerance over diversity of types During this austral summer, we will characterize and describe the distribution of Antarctic Peninsula plant communities near Palmer Station and identify significant environmental factors that affect plant growth and development. Ten plots of each plant community will be sampled, mapped, photographed, and permanently marked. To establish long-term trends in plant development, we will compare our data to previously examined and described plant communities near Palmer Station. Our objective is to increase the knowledge and understanding of antarctic plant communities and ecosystems, particularly in comparison with plant communities and ecosystems in arctic and alpine regions. We are also interested in evaluating the rate at which the plant communities recover after they have been disrupted. (S-033)



NSF photo by William Curtsinger.

On board the R/V Hero, a biologist sorts marine organisms gathered from the ocean floor. Study of these biological samples helps scientists understand the composition of the antarctic marine ecosystem.

Comparative behavioral and ecological studies of pygoscelid penguins in Admiralty Bay. *Wayne Trivelpiece, Point Reyes Bird Observatory.* Research has shown that variations in the populations of pygoscelid penguins (Adélie, chinstrap, and gentoo) may indicate similar variations in the southern ocean's krill stocks. However, more information is necessary to determine the role that members of this genus play in the marine ecosystem. We will continue to gather data on feeding preferences of adult pygoscelids and determine the amount of food required by these birds to raise their chicks. The Point Thomas area provides an ideal location for these studies as all three species breed sympatrically at that location. We also will investigate such factors as nest and colony site selection, nest site competition, predation pressure, and social behavior important to reproduction. Comparative studies of other more isolated rookeries will also be conducted to determine the effect man has had on the distribution and breeding habits of these species. (S-040)

Foods and feeding habits of asterozoan echinoderms. *John H. Dearborn, University of Maine, Orono.* As part of a 3-year project we have obtained detailed information on the food preferences, feeding behavior, and morphology of feeding structures of ecologically dominant asteroid and ophiuroid echinoderms found on the antarctic continental shelf. This season we will complete our field work on the extent to which these echinoderms feed directly and indirectly on krill, other zooplankton, benthic prey, and the derived detritus. Trawls, grabs, and underwater photography will be used to collect specimens and study the sea floor near Anvers Island. These data will be useful in understanding trophic interactions of benthic invertebrates, plankton, and fish in the antarctic marine ecosystem. (S-042)

Very-low-frequency (VLF) probing of the magnetosphere. *D.L. Carpenter and J.P. Katsufrakis, Stanford University.* At Palmer we will continue to study the effects of particle scattering from the earth's magnetosphere into the lower nighttime ionosphere. In this region the amplitude of subionospherically propagating fixed-frequency, very-low-frequency (VLF) signals may be perturbed as a result of burst-like particle precipitation. During periods of rapid changes in the field strengths of various transmissions received at Palmer, the Siple Station VLF transmitter will be operated to test for precipitation-induced wave effects as a frequency function on the Siple-to-Palmer path. Palmer direction-finding equipment will be used to detect the properties of magnetospheric whistlers that induce particle scattering in subionospheric propagation effects. We will continue to support such satellite programs as the Dynamics Explorer-1 and the SEEP (Stimulated Emission of Energetic Particles) project. VLF data will be acquired during passes of the SEEP satellite near the Palmer meridian. Through continuous chart recordings we will monitor special modulations of the Navy VLF transmitters for the SEEP project. Cooperative use of a riometer at the station may also provide us with a new understanding of particle scattering processes. (S-100B)

Air chemistry monitoring. *Elmer Robinson and W. Lee, Washington State University.* To obtain data on halocarbons, other trace gases, and Aitken nuclei, we will continue to operate an air chemistry monitoring station at Palmer Station. Analysis of air chemistry data will be augmented by meteorological observations, correlation with synoptic weather patterns, comparison with other northern and southern hemisphere stations, and other statistical assessments. Other analyses will be made on whole-air samples collected at Palmer and sent to Washington State University. (S-275B)

McMurdo Station and vicinity

Seasonal movements and interactions of the Weddell seal and the antarctic cod in McMurdo Sound. *Donald B. Siniff, University of Minnesota.* One objective of our research during the 1982-1983 austral summer is to learn more about the interaction between the Weddell seal (*Leptonychotes weddelli*) and its prey, particularly the antarctic cod (*Dissostichus mawsoni*). We will catch fish from various locations and use sonic tags to obtain under-the-ice movement patterns of Weddell seals and the antarctic cod. Working near McMurdo Station, we will document distributional patterns of immature Weddell seals between October and February, monitor the movements of radio-instrumented Weddell seals into and out of McMurdo Sound, and census seals at Hutton Cliffs. In January and February we will be on an icebreaker to census and tag seals near the ice edge. Several remote receiving-recording stations will be placed on prominent landmarks around McMurdo Sound to monitor long-term movement of radio-tagged seals. (S-004)

The role of glycopeptide antifreezes in freezing avoidance of antarctic fish. *Arthur L. DeVries, University of Illinois.* Living organisms adjust protein synthesis rates in response to environmental factors as a fundamental strategy for survival. During several seasons of research, we have discovered that all antarctic fish living in ice-laden shallow water possess either glycopeptide or peptide compounds that have protein antifreeze properties. Results from our experiments have indicated that there are eight different-sized glycopeptides, which lower the freezing point of body fluids below the temperature of the seawater (-1.9°C). This season we will catch various species of native antarctic fish to obtain tissue and fluid samples. Using these samples, we will determine the distribution of the different glycopeptides in all body fluids. We will also investigate whether intestinal glycopeptide antifreezes originate in the intestines or are absorbed from the blood. Continuing past experiments, we will study the relationship of the glycopeptide structure to its function. A comparison of how the antarctic fish *Pagothenia borchgrevinki* and the Atlantic fish *Microgadus tomcod* regulate levels of glycopeptide antifreezes will be conducted. While the antarctic fish maintains constant levels of the antifreeze compound in the uniform cold of antarctic waters, the tomcod produces different levels of antifreeze, correlating with the seasonal variation of temperature in its environment. (S-005)

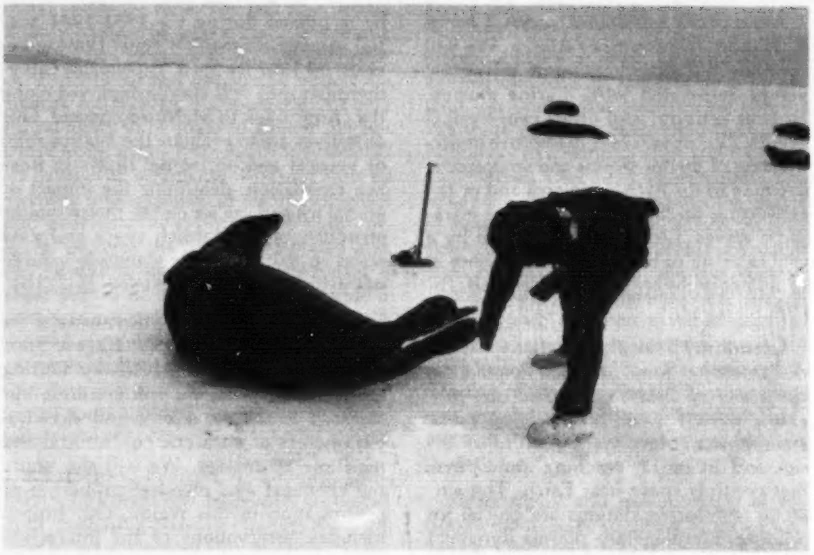
Population biology of south polar skuas. *David G. Ainley, Point Reyes Bird Observatory.* Although the breeding biology of south polar skuas, one of six major avian species of the pack-ice bird community in Antarctica, has been investigated by several researchers, our study focuses on population structure and demography. Surveys during past austral summers indicated that south polar skuas begin to breed between ages 5 to 9 and that breeding pairs stay together and maintain their breeding territories for as long as 15 years. Our research also suggests that these birds may survive for 35 years or more, although the population's age structure is irregular and affected by environmental factors. We will return to Cape Crozier to complete a survey of breeding areas started last season. We will also extend our survey to Cape Evans and the coast near Marble Point to look for previously banded birds and estimate survival, longevity, and emigration. (S-013)

Free diving Weddell seals: Fetal and maternal heart rate responses and arterial blood intermediary metabolites. *Warren M. Zapol, Massachusetts General Hospital.* In laboratories, simulated diving tests of pregnant Weddell seals have shown that the fetus responds with a slowed heart rate within a minute of the mother's response and before changes occur in fetal blood gas composition. The nature of the stimulus that slows the fetal heart rate is unknown and has not been studied in free-diving seals. We will test microelectronic computer instrumentation, developed to record fetal and maternal heart rates and seawater pressure in pregnant Weddell seals. We will correlate both heart rates with the depth and duration of each dive and obtain information about the relationship between fetal and maternal heart rates that may help to determine how the fetus becomes aware of the maternal diving response. The data we obtain will extend our understanding of not only fetal responses in diving mammals but also fetal cardiovascular responses in terrestrial mammals. (S-024)

Studies of blood serum from antarctic fish. *Robert E. Feeney, University of California, Davis.* Over the last 16 years we have studied blood serum proteins, particularly antifreeze glycoproteins, of fish living in the icy waters of McMurdo Sound. This austral summer we will catch fish, including *Trematomus borchgrevinki* and *Dissostichus mawsoni*, from McMurdo Sound to obtain more blood samples for this project. The blood will be centrifuged, and serums removed and frozen for transport to the United States. From these serums the antifreeze glycoproteins will be removed and individually tested in a pure form. Laboratory research will focus on the relationship of the chemical structure to the mechanisms by which the antifreeze glycoproteins lower the freezing temperature of water without affecting its melting temperature. (S-025)

Factors influencing the growth and development of sea ice microbial communities. *Cornelius W. Sullivan, University of Southern California.* Annual sea ice is a unique habitat for under-ice microbial communities, dominated by diatoms but including algae, bacteria, and protozoans. At the end of the summer the melting sea ice suddenly releases a surge of these physiologically active microorganisms into the water column and provides the basis for the subsequent phytoplankton blooms and a rich source of protein for pelagic grazers. This season we will investigate the factors influencing the growth and development of the sea ice microbial community. We are interested in the relationship between algal and bacterial components of this community and believe that the ice bacteria, which may be more active and have higher growth rates than other bacteria, in the water column enable high algal standing stocks to build up in the sea-ice lower layers. Perturbation studies will be conducted in McMurdo Sound to determine how light influences the growth rate of ice algae and how bacterial growth may be coupled to algal production. In addition to these field tests an environmental incubation chamber will be used to mimic light, temperature, and salinity features associated with the ice microenvironment. (S-039)

Geodetic and upper-atmospheric studies using satellites. *Arnold J. Tucker, University of Texas.* At McMurdo Station we will operate and maintain a geodetic satellite observatory to collect dual-frequency doppler data from polar-orbiting satellites. These satellites transmit similar data to South Pole Station on specific orbits, and data from both stations will help determine the spatial and time variations of the ionosphere and provide geodetic positioning controls. The study of variations in the earth's magnetic field at a 1,000-kilometer altitude will be augmented by telemetered magnetometer data acquired from other satellite passes. (S-051)



NSF photo by Russ Kinne.

Ward Testa of the University of Minnesota tags a Weddell seal on the sea ice near McMurdo Station. Sonic tags enable scientists to track seals swimming under the ice and moving in and out of McMurdo Sound. Receiving stations have been installed around McMurdo Sound so that long-term data on seal movements can be obtained.

Seismic studies in McMurdo Sound. *L. D. McGinnis, Northern Illinois University.* This season during a traverse of McMurdo Sound from Hut Point Peninsula, Ross Island, to New Harbor by way of Strand Moraine, we will take seismic measurements of the Earth's crust and upper mantle. We also will conduct additional seismic studies near Cape Roberts and take gravity measurements of Ross Island. The primary objective of our research is to obtain a crustal profile across the boundary between East and West Antarctica. We will determine the thickness of glacial and preglacial sediments and obtain a detailed stratigraphic and sedimentary record. From these data we will be better able to place the tectonic history of the Ross Embayment/Transantarctic Mountains in a global perspective. (S-053)

Seismotectonics and volcanology of Mt. Erebus and vicinity. *Juergen Kienle, University of Alaska.* To obtain a long-term record of seismic activity on Mt. Erebus, a study by U.S., New Zealand, and Japanese geologists was begun during the 1980-1981 austral summer. Continuing this investigation, we will expand the five-station seismic network already in place. The seismic network will help to locate microearthquakes precisely in order to define stress patterns and tectonically active areas of the volcano and to monitor long-term seismic and acoustic energy release and fluctuations. The system also provides us with data by which we can locate microearthquakes not occurring on Mt. Erebus and determine if these are tectonic. (S-067)

Volcanic and climatic record of ice cores. *Philip R. Kyle, New Mexico Institute of Mining and Technology.* Volcanic eruptions have been suggested as a cause of climatic cooling periods ranging in length from a few years to millions of years. Although short-term effects of volcanism on climate have been demonstrated in recent historic times, the effects over longer periods are not clear. Antarctic ice cores preserve a record of southern hemisphere volcanic activity and climate for approximately the last 100,000 years. To evaluate this record we will make laboratory analyses of ice cores taken at Byrd Station and Dome C. We will examine the cores for the volumetric size distribution and composition of tephra layers, which along with acid concentrations in the ice cores make up the volcanic record. To develop a baseline model for the laboratory research we will take shallow firn cores in the vicinity of Mt. Erebus on Ross Island. These cores will enable us to evaluate the dispersal of fine-grained tephra associated with post-eruptive activity. Ohio State University researchers will analyze the cores for particle grain size, and French scientists from the Laboratoire de Glaciologie will measure acidity, sulfate, and major ion chemistry. (S-081B)

Atmospheric infrasound studies. *Charles R. Wilson, University of Alaska.* We will continue our observations of infrasonic waves associated with marine storms, auroral activity, and other geophysical events. Our objective is to improve understanding of marine storms and stratospheric winds in the McMurdo area and of the generating mechanism for auroral infrasonic waves. Data will be collected by a spaced array of sensitive microphones at Windless Bight on the Ross Ice Shelf. (S-108)

Cosmic ray intensity variations. *Martin A. Pomerantz, Bartol Research Foundation, University of Delaware.* Cosmic rays provide a powerful tool for studying exotic astrophysical processes that occur on the sun and in its far reaching atmosphere that controls space near Earth. The antarctic monitoring stations are crucial for probing interplanetary plasma dynamics through observations of variations in relativistic (over 1 gigaelectron-volt) galactic cosmic rays. At McMurdo and South Pole Stations, we will continue our observations of cosmic radiation on a year-round basis and collaborate with the magnetospheric cusp program. Our objective is to obtain high quality observations with the ultimate time resolution that has been attained by other upper atmosphere programs at U.S. antarctic stations. (S-109A)

Pelagic research on ice shelf melting, 1982: sea ice. *E. L. Lewis and R. G. Perkin, Institute of Ocean Sciences, British Columbia.* Glaciologists believe that ice shelves may control the size of the west antarctic ice sheet, which in turn may relate to global sea-level changes. Investigators have suggested that basal melting of the ice shelves is a significant factor in their stability and that melting is controlled by oceanic heat from the north. This austral summer we will begin to monitor the heat flux into the region beneath the Ross Ice Shelf. We will deploy conductivity and temperature sensors in McMurdo Sound at 26 stations. These sensors will determine the geostrophic currents, thermohaline properties, and nature of any mesoscale eddies in the sound. We will also deploy current meters to obtain a time series of water movement and collect ice samples to investigate ice formation on the bottom of the sound and in the water column. The Erebus Ice Tongue will be examined for the effects of ice melting on the thermohaline structure of the water. Our investigation is coordinated with S-211B. (S-211A)

Ross Sea heat flux experiment: pelagic research on ice shelf melting, 1982. *Stanley Jacobs and Arnold Gordon, Lamont-Doherty Geological Observatory, and R. D. Pillsbury, Oregon State University.* From aboard the USCG icebreaker *Glacier* we will deploy long-term current meter/temperature/conductivity arrays, which will be recovered during the 1983-1984 austral summer, to monitor water flowing beneath the Ross Ice Shelf. Expendable bathythermographs will also be deployed along the cruise track in McMurdo Sound. Our objectives are to evaluate the relative roles of vertical and horizontal fluxes in Ross Sea circulation, determine the impact of glacial ice and sea ice on the thermohaline structure, and establish space and time scales so that natural or manmade induced perturbations may be modeled. (S-211B)

Winter meteorological phenomena of the McMurdo area. *Austin W. Hogan, State University of New York, Albany.* During the austral winter, we will continue our research to define aerosol and electrical parameters of antarctic continental and maritime air masses. We will also study the chemical and physical properties of precipitation in this region. Our project includes observations of the interaction among atmospheric aerosols, cloud processes, and transport mechanisms. The results should be useful for predicting the behavior of the same mechanisms in midlatitudes where experimentation is difficult due to interference from continental and pollution aerosols. (S-255A)

Air chemistry and meteorology. *Elmer Robinson, Washington State University.* A critical problem in atmospheric chemistry is the prediction of the effects of slow-reacting anthropogenic emissions on the atmosphere. Measurements in the southern hemisphere, including Antarctica, give a valuable base for atmospheric chemical modeling necessary to estimate long-term impacts. This project will provide data on hydrocarbons, halocarbons, and nitrous oxide. We will again collect air samples during transit in an LC-130 airplane from the United States to Antarctica. While at McMurdo Station, we will sample trace gases by helicopter from ground level to about 3,050 meters for vertical distribution. For approximately 2 1/2 months beginning early in the season, samples will be taken 3 times a week. Preliminary analysis of air samples taken in transit and from the McMurdo Sound region will be done in Antarctica. (S-275A)

Microphysics of cloud-aerosol interactions. *V. K. Saxena, North Carolina State University.* Large-scale motions determine when and where clouds will form and what their moisture content will be, but the microphysical processes that lead to ingestion of nuclei-rich air into the clouds are crucial in determining whether a cloud will produce rain, snow, or ice. In Antarctica coastal cloud-aerosol interactions are important in the summer hydrology of the coastal regions, the scavenging mechanisms in coastal clouds, and the chemistry of precipitation that accumulates on the surface. In November 1980 we collected samples of coastal-cloud water that showed evidence of biogenic material. Because of this discovery we have a new understanding of the microstructure of antarctic clouds and of the significance of biogenic sources. We think the source of this material is plankton in the southern ocean, which gets into the air when bubbles break on the surface of the sea. To test this hypothesis we will sample snow, ocean water, and cloud water from an aircraft capable of penetrating clouds. Data analysis will emphasize the microstructure of coastal clouds and the physiochemistry of aerosols that help to form clouds. (S-282)

Earth science research. *Takesi Nagata, National Institue of Polar Research, Japan.* In cooperation with the U. S. and New Zealand antarctic programs, we will continue to investigate the seismicity and volcanism of Mt. Erebus. Last austral summer a U. S. field party installed seismic stations on Mt. Erebus and one on Mt. Terror. Data from these stations were telemetered back to New Zealand's Scott Base where Japanese investigators collected the information and distributed it to the other participants. This austral summer we plan to install one or two more year-round stations. We also will install seven to eight temporary stations and activate five temporary stations installed last year. Observations from such densely installed stations during a 14- to 20-day period should provide us with detailed information on the velocity structures of Mt. Erebus and the precise hypocenter distributions. Gravity measurements taken at these stations will provide information on the volcano's structures. (S-305)

Victoria Land

Lake physiological adaptations. *Bruce C. Parker and George M. Simmons Jr., Virginia Polytechnic Institute and State University.* We will identify and evaluate physiological adaptations of algae important in the ecology of lakes in southern Victoria Land. Our research includes searching for algae specifically adapted to cold temperatures, high salinity, low light, low phosphate, and other nutrients, obtaining these algae in culture, and testing the extent of these physiological adaptations. During the 1981-1982 season we identified five types of living stromatolites in Lakes Bonney, Hoare, Vanda, and Fryxell. This season we will return to these lakes to determine how they contribute to the formation of geolipids—the precursors of fossil fuels. Four divers and other personnel will carry out the field work. In the laboratory, we will use carbon dating techniques on samples from previous years to determine the length of growth cycles. We also will continue to conduct analyses and experiments to determine whether or not the

U. S. Navy photo (XAM-0468-D-12-80) by Harry Weddington.

Ice cores and algae samples from the fresh water lakes of southern Victoria Land have provided biologists with new insights into the ecology and geochemistry of these ancient lakes. Above researchers from Virginia Polytechnic Institute and State University retrieve a core from Lake Bonney in Taylor Valley.

bottom layers of algae mats are living and to what extent bacteria play a role in decomposition. (S-002)

Endolithic microorganisms in ice-free valleys: primary producers in the antarctic desert ecosystem. *E. Imre Friedmann, Florida State University.* We will continue our study of the microbial flora living inside rocks in the ice-free valleys near the Asgard Range and in Beacon Valley. Our research includes lichen taxonomy, the chemistry, leaching, and biological weathering of rocks, nonphotosynthetic endolithic bacteria, micrometeorology, and the yearly accretion of nitrogen in rocks. This research will provide a more comprehensive understanding of cryptoendolithic microbial ecosystems, including their implications for earth sciences. (S-015)

Trace metal and nutrient behavior in the smaller lakes and meltwater streams of the antarctic ice-free valleys: Lakes Fryxell, Hoare, Miers, and Joyce. *William J. Green, Miami University.* The lakes of southern Victoria Land's ice-free valleys provide ideal conditions for investigating biogeochemical processes occurring in natural waters. They occupy enclosed basins, have a wide range of water chemistries, and are fed by only one or two meltwater streams during 6 to 8 weeks in the austral summer. We will begin a systematic study of the chemistry of Lakes Fryxell, Hoare, Miers, and Joyce. To gain more information on how trace metals are transported, removed, and remobilized in aquatic environments, we will establish trends in trace metal residence time. We will also investigate changes in biologically important elements as a response to changes in chemical conditions and determine which elements are present in concentrations and forms likely to be toxic to aquatic organism. Chemical data from meltwater streams, ice cover, and sediments will contribute to a general understanding of the trophic states and geochemical evolution of antarctic lakes. Because the lakes are isolated and can be studied as an entire system over a short period of time, they can provide a complete set of chemical data to be used for testing equilibrium and dynamic models of trace element and nutrient behavior. Our data will also add to the understanding of local biology, geology and climatology. (S-041)

Meteoritics. *William A. Cassidy, University of Pittsburgh.* Meteorites are useful in investigating possible changes through time in the meteoroid flux at earth, measuring the cosmic ray flux in past eras, searching events in which asteroid parent bodies were disrupted, and defining the abundances and characteristics of pre-solar-system organic molecules. Because high concentrations of meteorites have been found in the Allan Hills region of Victoria Land, one team will continue meteorite searches at a principal concentration site there and at Elephant Moraine, a site 80 kilometers north of Allan Hills and 70 kilometers west of Reckling Peak. They will also visit two ice patches, one 90 kilometers west of the Allan Hills and the other 50 kilometers northwest of Elephant Moraine, to search for more meteorite sites. Because ice movement and ablation rate data and ice analysis increase our understanding of the way meteorites concentrate, a second team in the Allan Hills will do glaciology and extend a triangulation grid previously established. A third team will search for meteorites in the Thiel Mountains and at Pecora Escarpment. (S-058)

Resource and radioactivity survey by airborne gamma ray spectrometry. *E. J. Zeller and G. Dreschhoff, University of Kansas.* We will set up a camp at Szabo Bluff to sample a nearby radioactive outcrop and extend our radiometric survey to other outcrops that can be reached from our camp. On Ross Island we will retrieve 35 radiation dosimeters (instruments which measure nuclear radiation over a given period) that were positioned last year on Observation Hill and at Trachyte Hill on Cape Bird. Although no mineral deposits of commercial value have yet been found in Antarctica, our survey helps us understand regional geology and resource potential. (S-059)

Kirkpatrick Basalt Group, northern Victoria Land. *David H. Elliot and Gunter Faure, Ohio State University.* Last summer we investigated Kirkpatrick basalt and Ferrar dolerite in the Mesa Range near the upper Rennick Glacier; we measured stratigraphic sections at seven locations and examined outcrops in three others. To extend our study, this summer we will investigate outcrops from the Monument Nunataks to Chisholm Hills and Pain and Gair Mesas. Our field examinations and laboratory studies will establish the degree of heterogeneity within individual lava flows, the mineralogical and chemical variations of lava sequences, the petrogenesis of the basalts, the paleomagnetic record, and the fossil record preserved in sedimentary interbeds in the flow sequence. Our work will contribute to a detailed understanding of the origin of the basalitic magmas and the conditions under which these magmas were extruded during the Jurassic. (S-060)

Stratigraphy and paleontology of the Gondwana rocks of southern Victoria Land. *Sankar Chatterjee, Texas Tech.* The Victoria (Permian and Triassic) and Ferrar (Jurassic) Groups of rocks are composed of a flat-lying, nonmarine sequence (the Beacon Supergroup) from Devonian or older to Jurassic in age. Our research will focus on the stratigraphy and paleontology of the Victoria Group because it was deposited before Gondwanaland broke up; the Ferrar Group, which marks the end of Gondwana sedimentation, will also be investigated. Working in the Allan and Carapace Nunataks of Victoria Valley, we will search for fossils of terrestrial vertebrates, emphasizing stratigraphic, taxonomic, and paleoecologic relationships. This region, which has not been searched for Gondwana fossils, may provide us with data to help resolve the controversy concerning the exact position and duration of contact (if any) between India and Antarctica. We will also study the source, origin, diagenesis, and environment of volcanic sediments of Gondwana rocks. Clay minerals will be used for detail interpretations of the provenance and paleoenvironment. (S-066)

Petrology and regional geology of early to middle Paleozoic magmatic rocks. *Edmund Stump and John Holloway, Arizona State University.* In northern Victoria Land, two chemically similar but temporally different groups of granitoid intrusions and an occurrence of extrusive rhyolite have been identified. Continuing last year's work, we will collect samples for laboratory analysis along the coast of northern Victoria Land at such locations as Moubray Bay, Tucker Glacier (west of Cape Hallet) and Spatulate Ridge, and along the coast from Tinker Glacier to Terra Nova Bay. We want to determine if the groups are chemically distinct and whether they were intruded continuously during the early to middle Paleozoic or in two episodes as limited data suggest. Laboratory investigations include petrography, mineral microprobe analysis, major- and trace-element geochemistry, and isotopic studies to characterize both types of rock groups. The project will extend our understanding of orogeny in the Transantarctic Mountains during the early to middle Paleozoic. (S-076A)

Uranium resources evaluation. *Edmund Stump, Arizona State University.* Complementing the S-059 investigation of radioactive outcrops in the Szabo Bluff region, a geologist will collect and identify the minerals present in pegmatite at this site. The objective is to learn more about the physical and chemical conditions under which the minerals were emplaced. (S-76B)

Volcanic geology of Marie Byrd Land and its relationship to glacial and tectonic history in West Antarctica. *Wesley E. LeMasurier, University of Colorado, Denver.* Working in the McMurdo Sound-Ross Sea area, we will collect hyaloclastite, tufflike deposits formed when basalt flows under water and ice and is fragmented, to compare with analogous rocks from Marie Byrd Land. We plan to visit Minna Bluff, Turks Head, Beaufort Island, and possibly Franklin Island. Hyaloclastites associated with pillow lavas (pillow-structured lavas presumably formed under water) from areas like Turks Head will be compared with hyaloclastites not associated with pillow lava from Marie Byrd Land. We will interpret the glacial and volcanic history recorded in the deposits to learn more about the past behavior of the West Antarctic ice sheet and to help predict its possible response to climatic warming. (S-073)

Contemporary geomorphic processes in ice-free valleys. *Michael C. Malin, Arizona State University.* Scientists have studied the geological and geomorphological history of the ice-free valleys of southern Victoria Land but have not addressed in detail the nature and rate of ongoing physical and chemical processes. We will examine wind erosion, desert pavement formation, chemical and physical modification of rock materials, and the relationships of these processes to landform development. One goal is to provide information for a variety of timescales, beginning with 2 months and continuing up to 20 years. Each site and the materials removed at selected intervals will be documented. We will use such analytical techniques as x-ray diffraction, optical inspection and mineralogical analysis, particle-size distribution and other sedimentological methods, and topographic and micro-topographic meteorological modeling. Scanning electron microscopy will play an important part in studying surfaces (exposed and freshly created) and crystal interfaces, as we attempt to identify initial phenomena associated with abrasion and physical and chemical alteration of rock material. The information we acquire should help in understanding how these valleys were formed, how they are changing, and how to predict the evolution of the region. (S-074)

Petrogenesis of the McMurdo Volcanic Group and the nature of the subcontinental mantle. *Philip R. Kyle, New Mexico Institute of Mining and Technology.* Studies of midocean ridge basalts, particularly along the Mid-Atlantic Ridge and its extension into Iceland, have indicated that the Earth's mantle may be heterogeneous. Recent models have suggested the subcontinental, lithospheric mantle along the Transantarctic Mountains is enriched in rubidium and has a high strontium isotopic ratio. The McMurdo Volcanic Group basanites contain ultramafic nodules, some of which may have an upper mantle origin and provide a way of assessing the nature of the mantle in the Ross Sea area. Ultramafic and crustal inclusions found in the basaltic zones along the foothills of the Royal Society Range and around McMurdo Station will be collected for laboratory studies. We will examine mantle-derived inclusions for geochemical heterogeneities that have been proposed for the subcontinental lithospheric mantle along the Transantarctic Mountains. In one location evidence of mantle metasomatism has been found, but we will be searching for other instances of this formation. To

NSF photo by Russ Kinne.

Two geologists and a biologist prepare to leave their main camp to collect data in northern Victoria Land. To reach remote areas of the continent, scientists use motor toboggans and sleds for transportation.

understand the distribution, chronology, and petrogenesis of Erebus and Melbourne volcanic province rock suites, we will map and sample late Cenozoic alkali volcanic rocks from the McMurdo Volcanic Group. We will also go to Mt. Erebus to continue surveillance of current volcanic activity and map around the summit flanks of the volcano and at Fang Ridge to evaluate the relationship of the volcano's geologic history to its current activity. (S-081A)

Magnetostratigraphy and sedimentology in ice-free valleys and McMurdo Sound. *Donald P. Elston, U. S. Geological Survey, Flagstaff, Arizona.* In an effort to decipher different aspects of late Cenozoic glacial history of the dry (ice-free) valleys and the Ross Sea, we will conduct stratigraphic, paleomagnetic, and sedimentologic investigations in eastern Taylor Valley, southern Victoria Land. Our work will concentrate on the stratigraphic and magnetostratigraphic correlations of subsurface and surface deposits underlying a late Pleistocene Ross Sea drift. During a similar project in 1980-1981, we drilled to a depth of 45 meters on a ridgeline in central Taylor Valley and discovered a sand body in this core and in surrounding outcrops. It may be possible to correlate the relationships between the terrestrial history of the dry valleys and the Transantarctic Mountains and the marine glacial history of the Ross Ice Shelf to global climate changes in the late Cenozoic period. We will complete eight 40- to 60-meter deep drill holes with two to three contingency holes in Taylor Valley. This work, which will be a joint U. S.-New Zealand project, will complement regional map studies by other U. S. investigators and develop a historical framework for an interval, which includes part of the Pliocene and most of the Pleistocene periods. (S-099)

Sediments deposited by marine ice sheets in the Ross, Weddell, Amundsen, and Barents Seas during the glacial maximum: a test of the maximum model. *Thomas B. Kellogg and Davida E. Kellogg, University of Maine.* Two models have been developed to describe glacial dynamics and the extent of the last glacial maximum (17,000 to 21,000 years ago). A maximum model suggests that marine-based ice sheets were of pivotal importance during this period. These ice sheets were characterized by convergent ice flow into ice streams probably buttressed by ice shelves, and were grounded to surfaces that remained below sea level after deglaciation and isostatic uplift. Their marine margins, located at the continental shelf, varied in response to sea level changes. The contrasting minimum model postulates small ice sheets, controlled by local precipitation and melting along their terrestrial margins. Since these two models respond differently to changes in sea level, precipitation, and isolation, validating one of the two is crucial. Data recently acquired in the Ross Sea area suggest that the maximum model is correct and that the West Antarctic Ice Sheet did advance to the continental shelf margin. We will complete our study of microfossils and sediments in cores from the Weddell and Amundsen Seas. Field work in Antarctica will be based in the McMurdo Sound area and the ice-free valleys of southern Victoria Land. We will assist S-099 investigators drilling in Taylor Valley by logging and describing cores and with preliminary analyses of microfossils in cored sediments. Also we will help G. Denton (S-056) with detailed geologic mapping near the Taylor Valley drilling site. Extensive sampling of the Sirius Formation, a lithified till or tillite apparently deposited early in the glacial history of the Transantarctic Mountains, will be carried out at Mt. Feather, Carapace Nunatak, and the Allan Hills. We will also collect some samples around McMurdo Sound and at Cape Bird. (S-209)

Remote or multiple sites

Biomass and metabolic activity of microplankton and nanoplankton in the ice-edge zone of the southern ocean. *Osmund Holm-Hansen, Scripps Institution of Oceanography.* During its circumantarctic cruise the USCGC *Polar Star* will travel near or within the ice-front zone, an area of very high biological activity. Over the last 25 years most southern ocean biological investigations have been conducted south of New Zealand and in the Scotia-Weddell Sea, but relatively little research has been done in the area between 0° and 150°E. The *Polar Star* work will provide us with an opportunity to expand our understanding of the dynamics of the food web in the ice-front zone and enable us to compare this information to what is known about the ice-free areas. Our investigation emphasizes the rate of primary production and the effect of varying temperature and light conditions on photosynthesis rates, the relative number and biomass of heterotrophic and autotrophic flagellates, the significance of the nonphotosynthetic microbial population to the routes and fluxes of organic carbon in the food web, and the distribution, biomass, and species composition of the phytoplankton population and its relationship to krill food requirements and preferences. To assist investigators studying krill-bird-mammal relationships, we will document the distribution and quantity of food sources for krill populations. (S-019)

Marine bird distribution in relation to krill in the East Wind Drift. *George L. Hunt, University of California, Irvine.* The East Wind Drift flows west along the antarctic coast, except where gyres in the Weddell, Ross, and Bellingshausen Seas divert it northward. Because little is known about the bird distribution in this region, during the circumantarctic cruise of the icebreaker *Polar Star* this season we will examine the distribution from Victoria Land (near the coast of Wilkes Land), Enderby Land, and Queen Maud Land to the Antarctic Peninsula. We will make a series of continuous 10-minute transects, supplemented by helicopter transects along the ship's cruise track. Data on bird species composition and numbers along with marine mammal and krill swarm distribution, ice conditions, and salinity-temperature measures will be collected. We will also investigate primary productivity, krill swarms, and the presence of birds and mammals in order to better understand the irregular distribution of higher marine vertebrate in relation to krill distribution. These data on the composition and distribution of the marine birds will provide information for an antarctic marine ecosystem model. (S-021)

Biological dynamics of the ice melt zone. *Walker O. Smith, University of Tennessee.* In the southern ocean, water near the receding ice edge is reportedly an area of high biological productivity. Although ice-edge phytoplankton blooms have been observed since early investigations of this region, little is known about their frequency, extent, formation, control, or chemical and biological properties. Some proposed explanations for the high productivity are water-column stability, ice-dampened wind stress, nutrient availability, and seed populations of phytoplankton released by melting ice. To test these hypotheses and to determine the controlling mechanisms that cause this heightened primary productivity, we will collect data on the degree, spatial extent, and temporal variability of phytoplankton blooms in the marginal ice zone. Transects will be run perpendicular to the ice front to determine how much meltwater influences bloom activity. Variations parallel to the ice front will be determined by following a zig-zag course for 200 to 500 kilometers along the ice edge. At stations along these transects we will gather data on the vertical distributions of temperature, salinity, dissolved nutrients, particulate carbon, nitrogen, silicon, chlorophyll, and phytoplankton taxa and measure rates of particulate carbon, nitrogen, and silicon produced by phytoplankton. (S-030)

Circumpolar analysis of the marine bird and mammal faunas of the pack ice. *Joseph R. Jehl, Jr., Hubbs-Sea World Research Institute.* During the circumantarctic cruise of the Coast Guard icebreaker *Polar Star*, we will document the distribution of marine bird and mammal faunas of the pack ice region, which until recently has been largely unexplored. An underwater acoustical device will enable us to monitor the presence of submerged mammals and to determine the relative effectiveness of visual and acoustical censusing. To extend our studies of killer whale biology in a geographic area for which no information is available, we will use hydrophones to record vocalizations and photography to document morphological variations. This information will help to clarify distribution, population structure, and the role of this predator. (S-034)

Censuses of seals in the eastern sector of antarctic pack ice. *Albert W. Erickson, University of Washington.* Increased demands for ocean resources will inevitably have an impact on the welfare of antarctic seal stocks. Besides direct exploitation of seals, commercial harvesting of krill and fish, biological contaminants acting directly or through the food chain, and physical impacts such as sounds may adversely affect the southern ocean seal population. Between 1967 and 1974 we extensively studied seals in the antarctic pack ice in order to develop a method for assessing seal population dynamics, to consider problems of stock discreteness, and to describe reproductive characteristics. This austral summer we will survey along the coast of East Antarctica, an area where censuses have not been conducted. The combined results of the earlier survey and this year's census will complete a circumantarctic assessment of seal abundance, distribution, and species composition. (S-044)

Air-sea aerosol transport rates in the southern ocean. *N. A. Wogman, Battelle Pacific Northwest Laboratories.* Data on aerosol transport across the air-sea interface provide information necessary to assess the impact of atmospheric pollutants on the sea. Little data are available on these transport rates in the southern ocean. We will collect samples between California and McMurdo Station to help define the air-sea interface and to determine the aerosol transport rate across this interface. Sampling will include collection of aerosols from large volumes of air, rainwater, and dry fallout, soluble and insoluble materials, and plankton from the near-surface water column. In our laboratories we will measure fallout and cosmic-ray-produced radionuclide concentrations in these samples. The resulting information will add to the data which we have collected during the past 15 years for the north and central Pacific and Atlantic Oceans. (S-049)

Mapping operations. *William J. Kosco, U.S. Geological Survey.* Two field engineers will conduct geodetic surveys in the ice-free valleys of southern Victoria Land to support antarctic mapping. Also, aerial photomapping will provide reconnaissance for potential new sites for glaciological research, for ongoing geology projects, and for the production of large-scale maps of the ice-free valleys in southern Victoria Land. (S-052B and C)

Late Cenozoic glacial history. *George H. Denton, University of Maine.* Research suggests that the marine ice sheet of West Antarctica expands to the edge of the continental shelves in the Weddell, Ross, and Amundsen Seas during glacial periods and recedes rapidly from these shelves during warm interglacial periods. Our research will focus on the late Quaternary history, the apparent instability of the marine-grounded ice sheet in West Antarctica, and, during the same geologic period, the apparent stability of the terrestrial ice sheet in East Antarctica. We will map glacial deposits in the ice-free valleys of southern Victoria Land. Our work will focus on the upper Taylor Valley, Marshall Valley, Quartermain Range, and Asgard Range. Some of our findings will be used to refine a three-dimensional ice-sheet reconstruction for the last ice-age maximum. Research results from this season along with data acquired during the 1981-1982 austral summer in northern and southern Victoria Land will refine knowledge of the Quaternary glacial-interglacial era of the West Antarctic Ice Sheet. (S-056)

Tectonic development of West Antarctica and its relation to East Antarctica. *Ian W.D. Dalziel, Lamont-Doherty Geological Observatory.* Over several years we have compiled data and conducted field research to gain an understanding of the relationship between East and West Antarctica through geologic time. Our previous investigations have focused on the Scotia Arc; however, more data on the region at the base of the Antarctic Peninsula extending to the Ellsworth, Thiel, and Whitmore Mountains is necessary to fully understand the relationship of East and West Antarctica. Although this season no field work will be conducted, fuel stations for a joint USARP-British Antarctic Survey investigation will be established in Ellsworth Land. Potential sites include Ellsworth Mountains, Martin Hills, Siple Station, and Mt. Smart. In 1983-1984 the field work will include geology, paleomagnetism, geochronology, and geophysics with radio-echo sounding and aeromagnetic surveys conducted by British geologists and geophysicists. (S-063)

Marine geology of the continental margin. *John B. Anderson, Rice University.* We will continue to survey and take piston cores from the continental margin while aboard USCGC *Glacier*. We will examine and describe both glacial and nonglacial sedimentation processes, take core samples of ancient sediments, survey iceberg sediment transport, and conduct closely spaced bottom sampling of benthic foraminifera. The continental margin survey includes constructing detailed bathymetric maps, plotting ice fronts, and acquiring geologic samples. From this data we learn more about the past environment of the southern ocean. Sample locations and descriptions of materials collected will be made available to other investigators through the Antarctic Marine Geology Research Facility at Florida State University and through publication. (S-207)

U. S. Navy photo (XAM 1101-B-01-81) by Michael L. Mullen.

Jeanette Thomas, Hubbs-Sea World Research Institute, recorded vocalization patterns of killer whales with sonobuoys each day during a January 1981 census of the marine mammals in the McMurdo Sound region. This austral summer Dr. Thomas and others from Hubbs-Sea World Research Institute will expand their census and vocalization investigation when they participate in the icebreaker Polar Star's circumantarctic cruise.

Chronometry and geochemistry of siliceous sediments. *David J. DeMaster, North Carolina State University.* In marine environments silica (SiO2) is an important nutrient used by such organisms as diatoms, radiolaria, siliceous sponges, and silicoflagellates for growth and formation of skeletal material. In antarctic continental shelf basins, biogenic silica makes up a large portion of diatomaceous sediments, which accumulate as rapidly as 3 millimeters per year. To assess the importance of these deposits to the marine silica budget and understand the accumulation of silica, we will collect box and piston cores from aboard the Coast Guard icebreaker *Glacier*. Our objectives are to establish accumulation rates for biogenic silica in antarctic continental shelf sediments and evaluate the importance of these deposits to the marine silica budget. Also we will investigate if rapidly accumulating siliceous sediments in the South Atlantic Ocean along the Polar Front are the result of surface activity or of bottom transport by deep ocean currents. (S-212)

Plankton and the marine geochemistry of radium, germanium, and barium. *Kent Fanning, University of South Florida.* Understanding the geochemistry of trace elements in the ocean may lead to a knowledge of the mixing rate in the oceans world wide. Like the distribution of nutrients (particularly silica) dissolved in seawater, concentrations of radium-226, germanium, and barium are usually depleted in surface waters and enriched in deep waters. Planktonic organisms may store these elements in skeletal structures, or protoplasm, although the uptake process is unclear. Because the southern ocean has large deposits of biogenic silica and is a major source of deep waters for the rest of the world, planktonic processes (related to the uptake of silicon and the three other elements) are important for determining the initial concentrations of biologically reactive substance in other areas of the ocean. While aboard the USCGC *Polar Star* we will collect seawater samples along the ice edge in areas of high biologically activity. These samples will be filtered for phytoplankton and zooplankton and will be used to estimate the uptake rates of radium-226, germanium, and barium. (S-213)

Katabatic winds. *Gerd Wendler, University of Alaska.* Katabatic, or gravity-driven, winds strongly influence the climate of Antarctica. To improve our understanding of these winds, three automatic weather stations were set up between Dumont d'Urville (on the coast) and Dome C (1,000 kilometers inland) to collect data for comparison with existing theoretical models. This study is a collaborative effort with Professor Poggi of France, who is establishing weather stations in and around Dumont d'Urville. We will continue to investigate blowing snow and its effect on katabatic winds. Vertical profile measurements of windspeed, direction, temperature, and dew point will be taken between Dome C and Dumont d'Urville Station and at South Pole Station. (S-277)

Comparing reproductive characteristics of brooding and nonbrooding echinoderms from the Kerguelen Archipelago. *John M. Lawrence, University of South Florida.* The influence of environment on evolution continues to be an important scientific question. Within the phylum *Echinodermata* (radially symmetrical coelomate marine animals including starfish, sea urchins, and other related forms) variations in reproductive strategies occur in polar regions. Direct development and brooding, which involves a large number of eggs developing without larval stages before becoming juveniles, is common. We believe that this variation, which may be a direct adaptation to the harsh southern ocean environment, represents a more energy-efficient life cycle than nonbrooding development that includes a feeding planktonic stage. Working with French scientists on Kerguelen Island we will analyze brooding and nonbrooding echinoderms. The development rate and reproductive success of brooding will be measured. Energy costs of direct development will be calculated by comparing the amount of organic material and caloric content of metamorphosed individuals.

Trace gas concentrations at the air-sea interface. *John Kelley and Thomas Gosink, Institute of Marine Science, University of Alaska.* As participants in the 1982-1983 cruise of Japanese icebreaker *Fuji*, we will collect data on trace gas concentrations in sea water and the atmosphere and will measure directly the exchange rate of carbon dioxide across the air-sea interface whenever possible. Our project, which is sponsored by the U. S. Department of Energy, will be carried out between Tokyo and the Japanese antarctic station Syowa (69°S 39°35'E). While on board the *Fuji*, we will collect air samples periodically each day and analyze them for carbon dioxide, methane, nitrous oxide, and other trace gases. Sea water will be drawn from bucket samples and analyzed for alkalinity, conductivity, temperature, salinity, and other factors. Near Syowa Station we will sample air and sea water in order to measure the carbon dioxide exchange rate. Our objective is to obtain data on exchange rates in the southern ocean and compare this information to similar arctic data. This comparison will help us refine our understanding of the effect of gobal carbon-dioxide levels on the polar regions.

Collection and analysis of automatic weather station data. *Charles R. Stearns, University of Wisconsin.* Although information taken from satellites on antarctic weather patterns is valuable, surface data are needed for confirmation. Automatic weather stations (AWS) measure surface pressure, air temperature, wind speed, and wind direction and transmit the data to satellites for interrogation by ground stations. To obtain reliable year-round surface data, we have installed AWS units around McMurdo Station and at Dome C, Byrd, Siple, and Dumont d'Urville Stations. This season we will service and recalibrate these units. One weather station at Arrival Heights near McMurdo will be moved to the Ross Ice Shelf, and storage batteries and solar panels will be installed in the Siple AWS so that it can operate throughout the winter. Four AWS units will be installed for us by the British Antarctic Survey this season in the Antarctic Peninsula region along the Weddell Sea. The data from These stations will be used to make case studies of barrier winds, foehn wind storms, terrain effects, and ice transport from the Weddell Sea. (S-283)

Changes in reproductive patterns of seals as indicators of shifts in ecosystem structure and function. *John L. Bengtson, University of Minnesota.* Reproductive patterns of seals, major krill predators, can serve as an index of food availability and relationships between krill-consuming populations in the antarctic marine ecosystem. As a part of this investigation last year we collected fur and leopard seals in the Antarctic Peninsula region. This year, with support provided by the British Antarctic Survey, we will examine seals near Bird Island (54°S 38°2'W). Although our research focuses on seal reproduction, the aim is to obtain information that will provide a better understanding of ecological relationships in antarctic waters. We will investigate changes in reproductive characteristics during the years following diminished whaling efforts and describe current reproductive parameters so that future investigators will have adequate data for studying reproductive features that may be affected by the development of a major krill fishery.

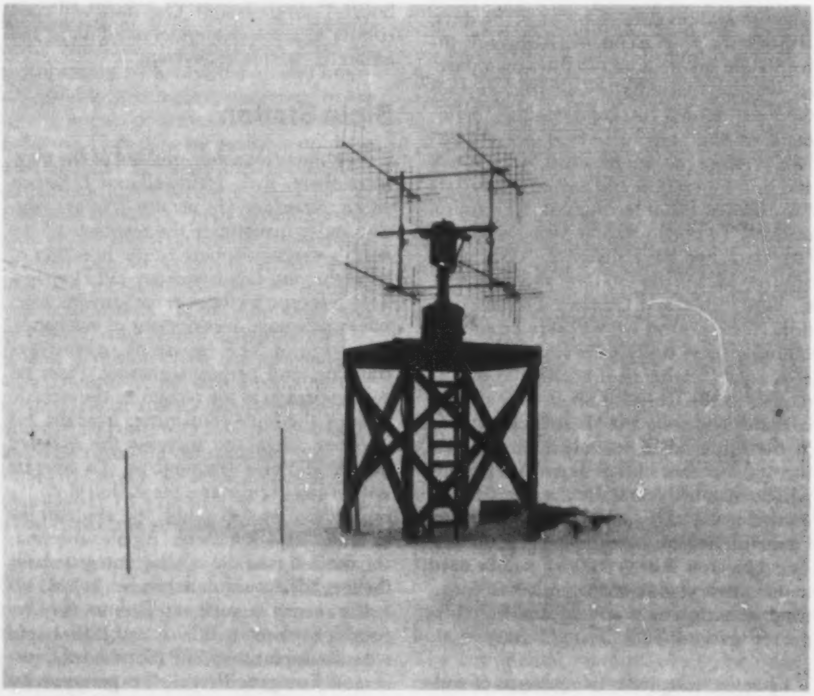
Distribution and abundance of antarctic and subantarctic phytoplankton. *Greta A. Fryxell, Texas A&M University.* High productivity in the southern ocean is well recorded; however, scientific documentation of this productivity and the environmental factors that regulate it is limited. With increased interest in krill as a commercial fishery, more detailed information on the structure and function of the antarctic marine ecosystem will be needed for rational managment. This year, with support provided by the British Antarctic Survey, we will collect data on the distribution and ecology of phytoplankton near South Georgia Island. Our data will contribute to a broader understanding of the antarctic marine ecosystem.

Siple Station

Very-low-frequency probing of the magnetosphere. *R.A. Helliwell and J. Katsufrakis, Stanford University.* We are continuing to investigate the response of the earth's magnetosphere to the injection of coherent very-low-frequency (VLF) waves. This response includes wave growth, spectral broadening, development of sidebands, triggering of VLF emissions, wave-wave coupling, and particle scattering. From recent experiences we recognize the need to operate the Siple transmitter near the 2-3 kiloherz range and increase the radiated power at those frequencies. To operate within (this range and the station's) power capabilities, we will double the length of the existing 21.4-kilometer dipole antenna; we also will raise the existing antenna above the level of accumulated snow. In 1983 we will transmit to such satellites as the Dynamics Explorer-1, ISIS-1, and ISIS-2, and we will support the SEEP (Stimulated Emission of Energetic Particles) experiment. By increasing the transmitter's radiated power capability we will be able to test newly designed wave-injection experiments. We will continue to do correlation experiments involving multiple techniques to study how various types of VLF waves scatter electrons into the ionosphere. As a part of particle precipitation studies, special subionospheric transmissions to Palmer, South Pole, and Halley Stations will be made. Continuous and synoptic broadband VLF recording will be carried out as required for long-term observations, plasmapause studies, and correlative support of particular projects. (S-100A)

Fluxgate magnetometer investigations at Siple and South Pole Stations. *L. J. Lanzerotti, Bell Laboratories.* At Siple Station over the last decade, a fluxgate magnetometer has been instrumental in studying hydromagnetic wave phenomena in the magnetosphere. In collaboration with University of Maryland scientists, riometers have been installed at four northern stations near the Siple conjugate region to investigate magnetosphere particle precipitation and the effects of waves on this phenomenon in the plasmapause region. This season we will continue to investigate the effects of hydromagnetic waves on magnetosphere particle precipitation at subauroral latitudes from Siple Station and the conjugate stations. A magnetometer, installed last season at South Pole Station, will be used for magnetic field studies that examine the types of hydromagnetic waves produced in the cusp region of the magnetosphere. Hydromagnetic wave data from South Pole will be used in conjunction with data from riometers, photometers, an ionosonde, and the all-sky camera to better understand the processes in the magnetospheric-cusp region. South Pole provides outstanding climatic conditions for extended optical observations. Correlations among optical measurements, particle precipitation, and hydromagnetic wave phenomena recorded by the magnetometer will give us useful data. (S-101)

Micropulsation research at Siple and South Pole Stations and preparation of a new micropulsation station for an unmanned geophysical observatory. *Laurence J. Cahill, University of Minnesota and Roger L. Arnoldy, University of New Hampshire.* We will continue operation of the digital micropulsation stations at Siple Station and Roberval, Quebec. Data from the magnetometer on the Dynamics Explorer satellite will be coordinated with data from these two ground stations and South Pole Station when the three stations and the satellite are alined along magnetic field lines. These data will enable us to compare wave frequencies, amplitudes, and polarizations on the ground and in the magnetosphere. A digital micropulsation station at South Pole Station will be used to study high-latitude and cusp ultra-low-frequency (ULF) waves and correlate ground ULF data with magnetic field observations made by the Dynamics Explorer. The station also operates in collaboration with very-low-frequency (VLF), riometer, optical, magnetometer, and particle measurements taken at South Pole Station. In another project, we will coordinate micropulsation data from Siple, Roberval, and South Pole with riometer and auroral light data to determine the source region of irregular, hydromagnetic wave pulsations, which may originate during magnetic activity near the auroral zone. Digital analysis will be used to determine the propagation characteristics of spectra and polarization of these events. By combining occurrence, propagation, and correlated observations, we hope to have a more detailed generation mechanism for these irregular, hydromagnetic wave pulsations. Data from the Dynamics Explorer, which has sensitive fluxgates capable of observing micropulsations up to a few hertz in frequency, will be useful in this study. In conjunction with other South Pole studies, we will investigate the relationships among particle precipitation, field-alined currents, optical emissions, and plasma waves. Working with S. Mende and R. Eather (projects S-104 and S-119) this season, we will construct and test a digital micropulsation station to be used in the prototype unmanned geophysical observatory at South Pole Station. (S-102)



NSF photo by Russ Kinne.

At Siple Station this satellite-tracking antenna is used in investigations of processes and interactions in the upper regions of the Earth's atmosphere. Some of the experiments at the station during 1982-1983 will be conducted in conjunction with 4 satellites, which will be orbiting over the polar regions.

Digital ionosonde studies from Siple Station and Roberval, Quebec. *J. R. Doupnik, Utah State University.* At Siple Station a computer-controlled ionospheric sounder, which complements existing facilities by measuring portions of the ionosphere's structure and dynamics, will be used to investigate the structure and dynamics of the midlatitude ionosphere and its coupling to the magnetosphere, the effects on the ionosphere of particles precipitated by naturally occurring and manmade very-low-frequency waves (VLF), ionospheric effects on low-frequency and VLF propagation, and the interactions between the ionosphere and magnetic variations. (S-120)

Amundsen-Scott South Pole Station

Human immune responses during bioisolation. *Harold G. Muchmore, Oklahoma Medical Foundation.* Contrary to the accepted concept that virus shedding usually ends early in convalescence, we have found by examining throat swabs taken from South Pole residents that viral persistence and shedding probably continue over a prolonged period. Samples from the station residents will be collected again during this austral summer and the winter isolation period. We hope to demonstrate the virus's presence in the primary nasopharyngeal specimen, to measure directly posterior nasal mucosal temperature in the extremely dry, cold climate of the South Pole, and to assess the impact of climate extremes on nasopharyngeal mucosa by serial measurements of the functions of nasal secretory immune system. Radioimmunoassay (RIA) and enzyme-linked immunosorbent assay (ELISA) techniques will be used to detect viral antigens in frozen sera and in specimens of nasopharyngeal secretions. Successful immunoassays should confirm the persistence of parainfluenza virus shedding and increase our understanding of the epidemiology of virus infections and the patterns of human immune response. (S-007)

Long-period gravity and seismic observations. *Leon Knopoff and W.D. Smythe, University of California, Los Angeles.* Because Amundsen-Scott South Pole Station is a seismically quiet platform, ideal for ultralong-period seismic and gravity observations, we will continue to measure long-period oscillations of the earth using two ultralong-period seismometers (modified La Coste-Romberg gravity meters). Also from this station, located on the path of the Mid-Atlantic Ridge and the East Pacific Rise, phase velocities sensitive to the middle-mantle structure under an oceanic ridge can be studied. The station's location, its symmetric position between the oceans, and the low noise at the observation site favor observations of long period tides and free oscillations. Analysis will provide us with a better understanding of the deep structure and lateral inhomogeneities of the earth. (S-050)

Geodesy and seismology. *William J. Kosco, U.S. Geological Survey.* Overflights of Navy navigational satellites will be tracked by two technicians at Amundsen-Scott South Pole throughout the year. These data will be used in studies of polar motion and ice movement. The South Pole seismometer will operate as a part of the Worldwide Standardized Seismology Network. (S-052A)

Very-low-frequency wave observations. *D.L. Carpenter and J.P. Katsufrakis, Stanford University.* We are investigating the physics of the magnetospheric cusp. In this region, solar wind plasma freely penetrates the magnetosphere and impinges on the earth's ionosphere, giving rise to a relatively localized region of particle precipitation and to a variety of plasma instabilities. Working with several other groups, we are attempting to define the characteristics of the southern polar cusp as well as to determine the morphology of substorm phenomena as they appear at the high-auroral-oval latitude of South Pole Station. Broadband very-low-frequency (VLF) wave data will be recorded; wave intensity in 10 selected narrow band channels will be sampled and recorded on a digital data logging system provided by the University of Maryland. While the Siple VLF transmitter is operating, we will make special ground recordings at South Pole in order to study how ionospheric changes affect subionospheric signal propagation between Siple and South Pole Stations. Ground VLF recordings, made when the Dynamics Explorer-1 satellite is operating over Antarctica, should provide important data for cusp and substorm phenomena investigations, and help determine the extent to which various classes of high-latitude VLF waves phenomena can penetrate the ionosphere. (S-100D)

Fluxgate magnetometer investigations at Siple and South Pole Stations. *L. J. Lanzerotti, Bell Laboratories.* For project description, see Siple Station section, project S-101.

Micropulsation research at Siple and South Pole Stations and preparation of a new micropulsation station an the unmanned geophysical observatory. *Laurence J. Cahill, University of Minnesota, and Roger L. Arnoldy, University of New Hampshire.* For project description, see Siple Station section, project S-102.

Auroral imaging at Siple and South Pole Stations. *S. B. Mende, Lockheed Palo Alto Research Laboratory.* In 1980 our collaborator R. Eather from Boston College (S-119) installed at South Pole Station a camera to monitor cusp auroral activity. This camera produces time-latitude "keograms" directly on film and provides a quick, easy method of finding the latitude of the cusp, an important but poorly understood boundary region of the Earth's magnetosphere. We will continue to operate the camera this season and check the equipment for needed adjustments. The system will be maintained by South Pole personnel during the austral winter. (S-104A)

Automatic geophysical observatory in Antarctica. *S. B. Mende, Lockheed Palo Alto Research Laboratory.* This season we will test a prototype automatic station developed for unmanned geophysical observations in the Antarctic. When perfected, these unmanned stations will make it feasible to obtain geophysical data from inaccessible areas. During the austral summer we will simulate transportation and field installation of the observatories near South Pole Station and during the winter conduct field tests. (S-104B)

Midday auroras. *Syun I. Akasofu, University of Alaska.* Over the last several years we have gathered data on the morphology of dayside auroras and their relationship to the interplanetary magnetic field. Using the all-sky camera at South Pole Station, we have been able to supplement photographs taken by the Defense Meteorological Satellite Program. Data from these two sources indicate that the auroral oval consists of topologically distinct dayside and nightside arc systems. Another important implication of our investigation has been the discovery that there are two dynamos in the magnetosphere. This season we will extend this work in an effort to improve our understanding of the Earth's magnetosphere, interactions between the solar wind and the magnetosphere, and interactions between the magnetosphere and the ionosphere. (S-106)

NSF photo by Russ Kinne.

A researcher releases a radiosonde weather balloon near the South Pole geodesic dome. With these balloons meteorlogists measure concentrations of ice crystals and atmospheric aerosols and variations in wind currents to determine the air circulation over the polar plateau.

Cosmic ray intensity variations. *Martin A. Pomerantz, Bartol Research Foundation, University of Delaware.* For project description, see McMurdo Station and vicinity, project S-109A.

Solar observatory. *Martin A. Pomerantz, Bartol Research Foundation, University of Delaware.* Approximately 6 kilometers from South Pole Station, we operate a solar telescope. A computer system, acquired and programmed by our Swedish collaborators, guides the telescope, rotates the solar image, maintains the selected field of view, and controls an observation schedule, which automatically shifts from one solar feature to another and produces photographic exposures and other records. This austral summer we hope to use new ancillary equipment and continue observations of solar features called super granulations. We will also obtain a new series of full-disk doppler-shift measurements, which enable us to probe the sun's interior structure and dynamics. Specifically the observations should provide data for models of the sun's interior temperature structure, define the lifetime of specific modes of solar oscillations, provide critical information about excitation and dissipation mechanisms of oscillations, probe the nature of meridional flows in the solar convection zone, and test the nature of oscillations with periods in excess of 10 minutes. To extend our understanding of the structure and nature of the sun's interior, we are interested in detecting and identifying gravity modes with precision similar to that already attained for acoustic modes. (S-109B)

Riometry in Antarctica and conjugate regions. *Theodore J. Rosenberg, University of Maryland.* A riometer, or relative ionospheric opacity meter, provides continuous data economically on temporal and spatial variations of energetic electron precipitation in the ionosphere. We will inspect the riometers and digital recording systems at South Pole and McMurdo Stations. Also at the South Pole, we will install a 30-megahertz riometer and data multiplexer as part of the Lockheed Research Laboratory's prototype automatic geophysical observatory (S-104B). A digital recording system will be installed at Siple Station, and another 30-megahertz riometer will be installed by Stanford University personnel (S-100B) at Palmer Station. The riometer measurements will provide information on electromagnetic particle precipitation and ionospheric perturbations associated with the cusp, auroral oval, and plasmapause regions of the magnetosphere. (S-111B)

Auroral imaging. *Robert H. Eather, Boston College.* We will install a modified version of our color, "keogram" camera at South Pole. This camera, which will continue operation during the 1983 austral winter, will continuously record the distribution of two auroral emissions along the magnetic meridian and monitor the character, position, and dynamics of polar cusp aurora. Because of its spectrum discriminating capability, this camera is uniquely suited for displaying the position and motion of the cusp and auroral oval. In addition to this project we will assist with construction and installation of a prototype automated geophysical observatory (S-104B) at South Pole. (S-119)

Extended observations of solar oscillations. *Robin Stebbins, Sacramento Peak Observatory.* The sun's normal modes of oscillation comprise a powerful diagnostic tool for studying a star's rotation, internal geometry, and internal physical processes. But, to be useful, the acoustic spectrum must be more highly resolved in frequency than is possible in a normal 12-hour observation period. Extended observations made at a polar site is one possible remedy to this difficulty. This austral summer we will use a compact, portable telescope to observe solar oscillations over several days at South Pole Station. Our observing technique analyzes solar-limb darkening for brightness oscillations. Data, acquired for as many extended viewing periods as possible, will be sent to Sacramento Peak Observatory for analysis. These observations will help us probe the sun's interior about which there is little direct information. (S-121)

Ionosonde studies of the cusp ionosphere. *F. T. Berkey and J. R. Doupnik, Utah State University.* Plasma instabilities and precipitation effects are produced in the ionosphere by solar winds as they penetrate the magnetosphere through the magnetospheric cusp. Particle precipitation in the cusp plays an important role in the physics of the magnetosphere-ionosphere system, perturbs the high-latitude dayside ionosphere, and produces optical emissions. Because these ionospheric disturbances cause electron density irregularities, reflected vertically as incident radio waves, we can measure these variations by means of an ionosonde (ionospheric sounder). These measurements will provide year-round, detailed information on structure and dynamics of the ionosphere. Our research will help determine the ionospheric signatures of cusp precipitation and the latitudinal and longitudinal structure of observed parameters within the cusp region, establish if the signatures are clear and repeatable, and estimate the size and location of the instantaneous cusp-produced ionospheric perturbation. Data will also be obtained on small-scale dynamics and structure of the cusp ionosphere and how these are related to other geophysical phenomena. (S-122)

Intermediate depth ice core drilling. *Karl C. Kuivinen, University of Nebraska.* Ice cores are valuable as a means of determining past atmospheric constituents and hence past weather and climate. Between mid-November and late December 1982 a 500-meter core will be obtained at South Pole Station for analysis in the field and the United States. (S-150)

Gas analysis of radioactive isotopes and general core processing of ice cores from South Pole Station. *Hans Oeschger, University of Berne, Switzerland.* In recent years the importance of ice cores for climatic research has grown because of the unique information they provide on the history of the Earth and planetary systems. New analytical techniques have made possible measurement of carbon dioxide contents of the air in the past and of changes in cosmic-ray-produced isotopes. We are particularly interested in how carbon dioxide and cosmic ray isotope levels relate to glaciation. The South Pole site was chosen because its temperature is extremely low and the annual accumulation is such that a 500-meter ice core will reach back several thousand years. Using modified versions of techniques developed for ice-core research in Greenland, we will assist with the analysis and processing of the 500-meter core drilled by project S-150. We will use a simplified system of visual stratigraphy and continuously measure solid electrical conductivity along the core. Because for carbon dioxide studies ice cores must not be fractured, we will test a device that slowly decompresses fragile ice cores in a pressure chamber. If the tests are successful, this method may be useful in future deep drilling. (S-170)

Micropartical analysis and glaciological interpretation of the 500-meter ice core from South Pole Station. *Ellen Mosley-Thompson, Ohio State University.* A relationship may exist among net accumulation rates, increased concentrations of insoluble particles, and reduced global temperatures. Analysis of late glacial sections of three ice cores has shown increased particle concentrations, which cannot be accounted for by just the reduced accumulation rates. Analysis of a 101-meter core retrieved near South Pole Station provided a 911-year record of concentrations of insoluble particles and net annual surface accumulation. This analysis also revealed that the particle concentration has an annual cycle, which can be used to construct a time scale and to estimate the annual variability in the average surface accumulation. This season we will analyze the 500-meter core to be drilled at South Pole. Because this core should provide a 6,200-year record, encompassing three neoglacial periods of mountain glacier expansion, we will have the opportunity to examine fluctuations in atmospheric concentrations of insoluble particles in the southern hemisphere over an extended time period. To obtain a spatial and temporal framework from which to interpret the microparticle variability in the 500-meter core, we will sample three 3-meter pits and associated 10-meter cores near the drill site and at least one site farther from the station. (S-171)

Aerosol transport processes. *Austin Hogan, State University of New York, Albany.* Several theories have been proposed to relate climate change to the variation of such physical properties as radiation transmission, conductivity, and cloud nucleation by the particulate matter suspended in the atmosphere. The ice in Antarctica acts as a sink and a temporary storage reservoir for particulate matter, certain gases, and vapors that precipitate from the air as it passes over the continent. Although the precipitation of these materials to the ice is important in maintaining the stability of several physical properties of the atmosphere, the precipitation mechanisms, which remove the material from the air, and the frequency with which the mechanisms act are not well understood. This austral summer from South Pole Station we will fly slow-rising meteorological balloons to measure the concentrations of ice crystals and aerosols and the variation of the wind currents to determine the circulation over the polar plateau. The measurements should enable us to form estimates of the ice's capacity as a sink for atmospheric contaminants. (S-255B)

Geophysical monitoring for climatic change. *James T. Peterson, Environmental Research Laboratories, National Oceanic and Atmospheric Administration.* Our field team will continue long-term measurements of trace atmospheric constituents that may influence climate. Two wintering personnel will measure carbon dioxide, surface ozone, winds, pressure, air and snow temperature, atmospheric moisture, and other trace constituents from the station's clean air facility. In support of this project, personnel at Palmer Station will collect carbon dioxide samples for us. (S-257)

Variability in the concentrations of atmospheric trace gases. *M. A. K. Khalil, Oregon Graduate Center.* Antarctica's relatively clean environment provides the ideal location for identifying anthropogenic trace gases in the atmosphere. Because the continent is isolated by thousands of miles from the nearest sources of trace gases, a compound found in the antarctic atmosphere probably is present in equal or greater concentrations everywhere. The objective of our project, which presently spans 6 years, is to sample various anthropogenic trace gases from South Pole Station to determine the temporal variabilities of concentrations. The results of this austral summer's research will enable us to set limits on certain variables in our calculations from past years. We will also measure flurocarbons, methane, and carbon monoxide. These measurements will expand scientific understanding of the impact of these gases on the world's environment. (S-262)

Measurement of atmospheric constituents. *David G. Murcray, University of Denver.* Antarctica may act as a sink for stratospheric constituents, particularly water vapor and HNO_3. South Pole Station is a unique ground site for this type of investigation because it combines high altitude and low water vapor concentrations, properties required for good infrared observations. Using instruments able to measure infrared radiation from the atmosphere, we will monitor the chemical composition of the atmosphere. During the austral summer we will perform preliminary tests with infrared atmospheric emission instruments to be used during the 1983-1984 austral winter and will determine the best location for these instruments. Although this system eventually will provide detailed data on the total density of atmospheric constituents in the air above South Pole Station, this season's objective is to improve the design of the instruments. (S-270)

Tracer experiment. *Paul R. Guthals, Los Alamos National Laboratory.* The ice-covered antarctic continent indicates changes in and controls climatic conditions. The regional weather patterns that transport energy and water to and from the continent and control the mass of snow and ice on the continent also transport pollutants (carbon dioxide and suspended particles) to Antarctica. To understand the way in which antarctic weather patterns influence global climate, we need to better understand the circulation systems controlling the continent's climate. Past research has indicated that the chemical composition of the aerosols at South Pole differ from winter to summer. This finding suggests that distinct seasonal circulation patterns may exist. To test this hypothesis we will monitor the transport of methane tracers to be released at selected locations during the 1983-1984 austral summer. We will test prototype air samplers at the South Pole and aboard LC-130 airplane. (S-284)

Midwinter airdrops at McMurdo and South Pole stations

For the second consecutive year the U.S. Air Force Military Airlift Command successfully completed a single-mission, two-location airdrop of cargo and mail at McMurdo and South Pole Stations. Despite high winds that lowered the temperature below -78.9°C, a C-141 airplane dropped 40 containers, weighing 23,984 pounds, at Williams Field, the ice runway near McMurdo Station on 22 June 1982. From McMurdo Station the airplane flew on to the South Pole. Seven containers, weighing 3,013 pounds, were dropped near South Pole Station, where the temperature had dropped to -81.7°. Ground crews at both stations successfully recovered all of the containers, although one container was slightly damaged in the drop at South Pole Station.

Except for radio communication, the airdrops were the only contact that station personnel have had with the outside world since the stations began winter operations in February (South Pole) and March (McMurdo).

South Pole record low temperature

On 23 June 1982 wintering personnel at Amundsen-Scott South Pole Station recorded a new low temperature: -82.8°C (-117.4°F). This low, recorded under clear skies with a light wind blowing, broke the previous record of -80.7°C (-113.3°F) set in July 1956.

As cold as it was at South Pole Station, this temperature was not the lowest ever recorded in Antarctica. On 24 August 1960, scientists at the Soviet station Vostok—about 1,400 kilometers inland—reported a low temperature of -106°C (-127°F).

The Antarctic Plate: a global perspective. Report on a Geological Society of America Penrose conference

Edward Wilson's discovery in February 1912 of fossilized leaves of the permian plant *Glossopteris* clearly tied Antarctica to the other southern continents and to the Gondwana floral province, but it was the great South African geologist Alex. L. Du Toit who recognized that Antarctica is the "cornerstone" of Gondwanaland. He predicted that the geology of the continent—poorly known at that time 50 years ago—would bear great similarities to the other southern continents. These predictions have come true.

Much has been learned about Antarctica in the last 70 years, particularly since the International Geophysical Year when systematic exploration of the continent started. The basic structure and geological history are now known, but with 98 percent of the continent covered by ice, much of Antarctica remains *terra incognita.* The advent of plate tectonic theory in the 1960s and the more recent recognition that Antarctica plays a central role in a variety of geological problems led to a proposal to the Geological Society of America for a Penrose Conference on the Antarctic Plate.

The Geological Society of America has sponsored Penrose Conferences since 1969. At these meetings U. S. and foreign geologists exchange ideas and information in an effort to develop new ways of considering important questions and to provoke new lines of research. The objective of the 1982 Penrose Conference was to advance understanding of the history and evolution of the antarctic tectonic plate, with special focus on plate interaction, and associated magmatic and tectonic processes, paleocirculation, paleoclimate, paleobiogeography and the history of the Pacific Ocean. Understanding the geologic history and structure of the continent and the surrounding ocean is significant to many earth scientists, even those who have never conducted research in Antarctica or the southern ocean.

The conference was held 11-16 April 1982 at Skyland Lodge, Shenandoah National Park, Virginia, the site of several orientation programs for the U.S. Antarctic Research Program during the 1960s. Of the 75 participants, 19 (including nine from industry) had never set foot on the antarctic continent or been a member of an antarctic program, and 21 were from 9 foreign countries.

Antarctica holds the key to several major geological problems that extend beyond the confines of the continent and the jigsaw puzzle of Gondwanaland. Some significant examples are:

- All calculations involving plate interactions on a global scale involve assumptions about the relationship between East and West Antarctica during the Mesozoic and Cenozoic.
- Antarctica, together with southern Africa, was the focus of the magmatic and tectonic phenomena associated with the initial breakup of the Gondwanaland plate during the Jurassic. Consequently, Antarctica has a central role in the deep-seated processes, presumably in the mantle, responsible for disruption of the supercontinent.
- Understanding the geometry and timing of antarctic plate growth is crucial to understanding the development of circulation in the southern oceans and of paleoclimate before, during, and subsequent to the Cenozoic glacial maxima.
- The interrelationships of land masses within and around the continent have an important bearing on paleobiogeography, for example, the distribution of marsupials.

Conference sessions were organized with lead speakers, shorter solicited contributions, and discussion from the floor. A few of the highlights will serve to show the purpose and direction of the conference. A more comprehensive account with a slightly different perspective will be published in *Geology*.

The reconstruction of Gondwanaland must be a central point in placing Antarctica in a global context. The map that is being prepared from the 1979 "Reunite Gondwanaland" workshop, convened at the University of the Witwatersrand, reemphasizes that although the general arrangement of Precambrian shield areas is undisputed, the nature of the "Pacific" margin is still hotly contested. The crustal structure of West Antarctica is critical to this problem and bears on the evolution of the plate since breakup in Early to Middle Jurassic time approximately 180 million years ago. The broad overview of continental breakup pointed up significant differences in the tectonic setting and chemistry of the basaltic igneous rocks between the various continents, in particular Antarctica with respect to southern Africa. The causes and mechanisms are still far from clear, though few would dispute that heat was the ultimate driving force.

The evolution of the Antarctic Plate can be considered in three parts: the growing ocean floor that forms part of the plate, the West Antarctic region, and the continental margin. The microplate development and evolution of West Antarctica bear directly on long-recognized, apparent anomalies such as the geology of the Ellsworth Mountains and the nature of the subglacial deeps. The antarctic continental margin differs from all others because the depth at the shelf break is about 500 meters, in contrast to 200 meters elsewhere—is this a function of ice loading or lack of sediment deposition since the inception of the ice sheet?

For the most part, the shelf around the continent contains the only extensive and accessible geological record for the last 150 million years and with the deep ocean basins constitutes our only source of information for events leading up to the present day. The deep ocean floor provides data on the relative changes in position of the southern continents since breakup. This sedimentary record reflects the changing ocean boundaries, climatic perturbations, and circulation changes, the most significant of which is the inception of the Antarctic Circumpolar Current.

Linked to these physical changes in a way that is still disputed is the formation of Antarctic Bottom Water that results from an extensive sea-ice cover. The sediments of the southern oceans contain a long record of climatic change dating back some 100 million years, but not until 40 million years ago can specific changes be inferred to be causally related to events around Antarctica. The questions still remain: when did the first ice sheet come into existence, did mountain glaciation predate ice sheet formation, what role did uplift of the Transantarctic Mountains play, and when and how did the West Antarctic ice sheet form? The changing patterns of land and shallow sea connections have played a significant role in the evolution of southern hemisphere biota. Mention need only be made of the question of marsupial paleobiogeography and the evolution of the endemic high latitude faunas around the continent today.

In the final session on problems and future directions the broader views of the participants were reflected by Ron Oxburgh, University of Cambridge, a newcomer to the problems of earth sciences in Antarctica. He suggested that the greatest rewards will come through identifying those problems that can best be investigated in Antarctica. What experiments has nature conducted in Antarctica? In what way is Antarctica important, if not crucial, for understanding global geological processes? Within the framework of these questions, there was a consensus that crustal structure, the geological record of the continental shelves, and certain specific problems such as the Ferrar Supergroup will lead to greatest returns. Also, remote sensing in the broadest sense of the word will provide the data allowing the next major advance in our understanding of Antarctica.

This Penrose Conference was supported by National Science Foundation grant DPP 81-15101. Additional help was provided by Atlantic Richfield Company, Chevron Overseas Petroleum Inc., Cities Service Company, S.N. Elf Aquitaine, Marathon Oil Company, and Shell Oil Company.

—I.W.D. Dalziel, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York, and D. H. Elliot, Institute of Polar Studies, Ohio State University, Columbus, Ohio.

Naval antarctic operations change command

Both U. S. Navy organizations that support the United States Antarctic Research Program changed commands in 1982.

Commander Paul R. Dykeman turned over to Commander Michael J. Harris command of the Antarctic Development Squadron Six (VXE-6) at a ceremony on 28 May 1982. The ceremony, held at the Naval Air Station, Point Mugu, California, included speeches by Captain Thomas A. Stanley, Chief of Staff for the Commander of the Anti-Submarine Warfare Wing, U. S. Pacific Fleet and Dr. Edward P. Todd, Director of the Division of Polar Programs, National Science Foundation. VXE-6 operates the LC-130 airplanes and UH-1N helicopters in Antarctica.

Commander Harris, a graduate of the University of Kansas, joined VXE-6 in 1980 as operations officer and became executive officer in May 1981. Commissioned after completing Officer Candidate School, he entered flight training in April 1964 and was assigned as a navigator to the Airborne Early Warning Barrier Squadron Pacific, based at Barbers Point, Hawaii. Since 1965 his assignments have included navigation, schedules and maintenance officer, Patrol Squadron Six at Barbers Point; executive officer, Naval Facility, Point Sur, California; project manager for Third Fleet Tactical Development and Evaluation programs; and operations and maintenance officer, Patrol Squadron Nine, Naval Air Station, Moffett Field, California. Commander Harris has received the Navy Commendation Medal, Navy Unit Commendation, National Defense Medal, Sea Service Medal, and two Navy Achievement Medals.

Commander Dykeman, who joined VXE-6 as operations officer in 1979, had assumed command of the squadron in May 1981. He currently is stationed at the Industrial College of the Armed Forces at Fort Lesley J. McNair in Washington, D.C.

On 26 July 1982 Captain Brian H. Shoemaker, U. S. Navy, replaced Captain Jare M. Pearigen, U. S. Navy, as Commander of the U. S. Naval Support Force, Antarctica (NSFA). The change of command ceremony took place at the U. S. Naval Construction Battalion Center in Port Hueneme, California. Dr. Edward P. Todd, Director of the National Science Foundation's Division of Polar Programs, participated in the ceremony. The Naval Support Force, Antarctica, plans and directs U. S. Navy logistics in Antarctica.

Commissioned in 1960 after graduating from the University of California at Berkeley, Captain Shoemaker has been assigned several times to the polar regions. In 1966 he joined the VXE-6 squadron and wintered in Antarctica as assistant officer in charge of the naval detachment at McMurdo Station. While working on his master of science degree in oceanography at the Naval Postgraduate School, he made two trips to the central Arctic Ocean to conduct oceanographic research from stations in the pack ice. In 1974 he assumed command of the Naval Arctic Research Laboratory at Point Barrow, Alaska. During this tour he commissioned 14 ice stations and managed 21 field research camps around the Arctic Ocean. His other duty tours have included assignments in the Philippines, western Pacific Ocean, and Indian Ocean. Prior to assuming command of the Naval Support Force, Antarctica, Captain Shoemaker was at the National War College in Washington, D.C.

Captain Pearigen, who assumed command of NSFA in June 1980, will be with the Office of the Assistant Secretary of the Navy (Research, Engineering, and Systems) and has been assigned to the National Science Foundation's Division of Polar Programs. While assigned to the National Science Foundation, he will act as liaison between the military and civilian components of the U.S. Antarctic Program.

Spain joins in support of Antarctic Treaty

On 31 March 1982 Spain acceded to the Antarctic Treaty, raising the number of nations that recognize the Treaty to 26. Other acceding nations include Brazil, Bulgaria, Czechoslovakia, Denmark, the German Democratic Republic, Italy, the Netherlands, Papua New Guinea, Peru, Romania, and Uruguay. These acceding nations agree to abide by the Treaty, but do not participate in its operation. The remaining contracting nations, or consultative parties are Argentina, Australia, Belgium, Chile, the Federal Republic of Germany, France, Japan, New Zealand, Norway, Poland, the Republic of South Africa, the Union of Soviet Socialist Republics, the United Kingdom, and the United States. Representatives of these nations participate in periodic consultative meetings to formulate recommendations aimed at furthering objectives of the Treaty.

Foundation awards of funds for antarctic projects, 1 January to 30 June 1982

Following is a list of National Science Foundation antarctic awards made from 1 January to 30 June 1982. Each item contains the name of the principal investigator or project manager, his or her institution, a shortened title of the project, the award number, and the amount awarded. If an investigator received a joint award from more than one Foundation program, the antarctic program funds are listed first, and the total amount of the award is listed in parentheses. Within the parentheses, "A" indicates that the Division of Polar Programs provided additional funding for arctic research; "E" indicates that the Division of Earth Sciences also provided funding. Awards initiated by the Division of Polar Programs contain the prefix DPP in the award number, those by the Division of Physiology, Cellular, and Molecular Biology the prefix PCM, and those by the Division of Earth Sciences the prefix EAR.

Glaciology

Bentley, Charles R. University of Wisconsin, Madison, Wisconsin. Completion and publication of Ross Ice Shelf Geophysical and Glaciological Survey final report. DPP 81-19989. $51,108.

Fireman, Edward L. Smithsonian Institution, Cambridge, Massachusetts. Composition and carbon-14 content of gas in ice at antarctic meteorite sites. DPP 80-25234. $66,450.

Kyle, Philip R. New Mexico Institute of Mining and Technology, Socorro, New Mexico. Volcanic and climatic record of antarctic ice cores. DPP 80-21402. $66,549.

Mosley-Thompson, Ellen. Ohio State University, Columbus, Ohio. Microparticle analysis and glaciological interpretation of the 500-meter ice core from South Pole Station. DPP 80-18860. $42,600.

Stuiver, Minze. University of Washington, Seattle, Washington. Oxygen isotope analysis of ice and permafrost cores. DPP 80-19756. $93,389.

Whillans, Ian M. Ohio State University, Columbus, Ohio. Glaciology near Dome C, East Antarctica. DPP 79-20824. $17,947.

Atmospheric sciences

Cahill, Laurence J. University of Minnesota, St. Paul, Minnesota. Micropulsation research at Roberval, Quebec, and at Siple and South Pole Stations, Antarctica. DPP 81-20957. $41,816. ($191, 816A).

Carpenter, Donald L. Stanford University, Stanford, California. Very-low-frequency probing of the magnetosphere from Palmer Station. DPP 79-24600. $118,000.

Carroll, John J. University of California, Davis, California. Studies of atmospheric energy transfer processes at the South Pole. DPP 81-16747. $70,000.

Doupnik, Joe R. Utah State University, Logan, Utah. Digital ionosonde studies of the ionosphere from Siple Station, Antarctica and Roberval, Quebec. DPP 81-00220. $24,818. ($194,818A).

Guthals, Paul R. Los Alamos Scientific Laboratory, Los Alamos, New Mexico. Antarctic atmospheric tracer experiment. DPP 81-18562. $18,800.

Helliwell, Robert A. Stanford University, Stanford, California. Active and passive very-low-frequency wave-particle interaction experiments on the magnetosphere from Siple Station. DPP 80-22282. $326,160.

Khalil, M. A. Oregon Graduate Center, Beaverton, Oregon. Atmospheric variability in the concentrations of trace gases over Antarctica. DPP 81-08684. $40,923.

Kinter, Paul M. Cornell University, Ithaca, New York. Data analysis of dc and ac electric fields and magnetic fields in the ionosphere above the antarctic very-low-frequency transmitter. DPP 80-23968. $32,574. ($66,574A).

NSF photo by Russ Kinne.

A UH-1N helicopter, flown by a pilot of the U. S. Navy's VXE-6 squadron, lands near a tent camp by Lake Vida in Victoria Valley. Scientists, working in the field near McMurdo Station, are transported and supplied by Navy helicopters.

Lanzerotti, Louis J. Bell Telephone Laboratory, Murray Hill, New Jersey. Magnetic field investigations at Siple and South Pole Stations. DPP 81-20008. Logistic support only.

Mende, Stephen B. Lockheed Missile and Space Company, Inc., Palo Alto, California. Antarctic auroral imaging. DPP 80-16574. $59,810.

Pomerantz, Martin A. Bartol Research Foundation, University of Delaware, Newark, Delaware. Solar seismology at the South Pole: studies of solar oscillations. DPP 81-19627. $99,195.

Pomerantz, Martin A. Bartol Research Foundation, University of Delaware, Newark, Delaware. Survey of the galactic submillimetric emission in the southern hemisphere. DPP 81-20258. $18,900.

Pomerantz, Martin A. Bartol Research Foundation, University of Delaware, Newark, Delaware. Investigations of cosmic ray intensity variations in antarctica. DPP 79-23218. $176,220.

Rosenberg, Theodore J. University of Maryland, College Park, Maryland. Investigation of signal anomalies in subionospheric very-low-frequency radiowave propagation using data from U.S. antarctic stations. DPP 80-12941. $16,600.

Wilson, Charles R. University of Alaska, Fairbanks, Alaska. Infrasonic wave observations made at Windless Bight near McMurdo Station. DPP 81-20734. $20,622.

Wilson, Charles R. University of Alaska, Fairbanks, Alaska. Logistical support for infrasonic wave research at Windless Bight. DPP 81-21669. Logistic support only.

Biology and medicine

Baust, John G. University of Houston, Houston, Texas. Symposium on water and adaptation: are there common denominators?; Houston, Texas, 27 June-1 July 1982. PCM 82-01213. $1,000. ($4,000).

Dearborn, John H. University of Maine, Orono, Maine. Foods and feeding habits of antarctic asterozoan echinoderms. DPP 79-21537. $66,914.

Feeney, Robert E. University of California, Davis, California. Collection of blood serum from antarctic fishes. DPP 81-16963. $9,338.

Fryxell, Greta A. Texas A&M University, College Station, Texas. Distribution and abundance of antarctic and subantarctic phytoplankton. DPP 80-20381. $44, 208.

George, Robert Y. University of North Carolina, Wilmington, North Carolina. Symposium on the biology of antarctic krill, *Euphausia superba*. DPP 82-05855. $22,936.

Green, William J. Miami University, Oxford, Ohio. Aspects of trace metal and nutrient behavior in the Onyx River and Lake Vanda. DPP 79-20860. $15, 429.

Hamner, William M. University of California, Los Angeles, California. Behavior of *Euphausia superba* in Antarctica. DPP 80-23851. $87,687.

Haschemeyer, Audrey E. Hunter College, New York, New York. Adaptations in protein metabolism of antarctic organisms. DPP 80-21454. $112,324.

Huguenin, Robert L. University of Massachusetts, Amherst, Massachusetts. Dissertation research on the biology of soil bacteria indigenous to antarctic ice-free valleys. DPP 81-20605. $9,000.

Lawrence, John M. University of South Florida, Tampa, Florida. Reproductive characteristics of brooding and non-brooding echinoderms. DPP 81-08992. $19,982.

Murrish, David E. State University of New York, Binghamton, New York. Thermoregulatory mechanisms in antarctic penguins. DPP 80-19988. $43,639.

Parker, Bruce C. Virginia Polytechnic Institute, Blacksburg, Virginia. Antarctic lake physiological adaptations. DPP 79-20805. $106,805.

Rausch, Robert L. University of Washington, Seattle, Washington. Helminth parasites of birds in the Palmer Archipelago. DPP 81-15975. $32,990.

Shulenberger, Eric. San Diego Society for Natural History, San Diego, California. Analysis of antarctic zooplankton samples. DPP 81-20492. $18,384.

Siniff, Donald B. University of Minnesota, Minneapolis, Minnesota. Seasonal movements and interactions of Weddell Seals *Leotonychotes Weddelli* and antarctic cod *Dissostichus mawsoni* in McMurdo Sound, Antarctica. DPP 80-20097. $143,681.

Smith, Walker O. University of Tennessee, Knoxville, Tennessee. Phytoplankton dynamics of the antarctic ice melt zone. DPP 81-19572. $109,996.

Wormuth, John. Texas A&M University, College Station, Texas. Analysis of antarctic zooplankton samples. DPP 81-21358. $25,586.

Zapol, Warren M. Massachusetts General Hospital, Boston, Massachusetts. Diving physiology of the fetal Weddell seal. DPP 81-00212. $24,846.

Earth Sciences

Askin, Rosemary A. Colorado School of Mines, Golden, Colorado. Cretaceous and early Tertiary palynology of the James Ross Island area, Antarctica. DPP 82-20095. $49,692.

Cassidy, William A. University of Pittsburgh, Pittsburgh, Pennsylvania. Antarctic search for meteorites. DPP 78-21104. $69,408.

Chatterjee, Sankar. Texas Tech University, Lubbock, Texas. Stratigraphy and paleontology of Gondwanaland rocks of Antarctica. DPP 81-07152. $35,000. ($37,000).

Collinson, James W. Ohio State University, Columbus, Ohio. Stratigraphy, sedimentology, and sedimentary petrology of the Permian-Triassic Gondwanaland sequence in northern Victoria Land. DPP 80-20098. $19,999.

Dahl, Peter S. Kent State University, Kent, Ohio. Group travel for U.S. participants in the Fourth International Symposium on Antarctic Earth Sciences, Adelaide, Australia (16-20 August 1982). DPP 82-00204. $30,020.

Elliot, David H. Ohio State University, Columbus, Ohio. Geologic and paleontologic history of the James Ross Island Basin, northern Antarctic Peninsula. DPP 80-20096. $55,000.

Elliot, David H. Ohio State University, Columbus, Ohio. Kirkpatrick Basalt Group rocks from northern Victoria Land. DPP 80-21401. $28,000.

Hammer, William R. Wayne State University, Detroit, Michigan. Vertebrate paleontology of the Permian-Triassic Gondwanaland sequence in northern Victoria Land. DPP 80-19996. $11,990.

Knopoff, Leon. University of California, Los Angeles, California. Ultra-long period seismic and gravity observations at South Pole Station. DPP 81-17325. $159,318.

Kyle, Philip R. New Mexico Institute of Mining and Technology, Socorro, New Mexico. Petrogenesis of the McMurdo Volcanic Group and the nature of the subcontinental mantle in Victoria Land. DPP 80-20002. $54,080.

LeMasurier, Wesley E. University of Colorado, Denver, Colorado. Volcanic geology of Marie Byrd Land and its relationships to glacial and tectonic history in West Antarctica. DPP 80-20836. $21,000.

Lipschutz, Michael E. Purdue University, Lafayette, Indiana. Weathering and chemistry of antarctic meteorites. DPP 81-11513. $14,500. ($29,000E).

Mayewski, Paul A. University of New Hampshire, Durham, New Hampshire. History and significance of ice mass fluctuations in Victoria Land. DPP 80-19982. $21,737.

Quaide, William L. National Aeronautics and Space Administration, Washington, D.C. Support of the lunar and planetary institute. DPP 82-09969. $34,600.

Southard, Rupert B. U. S. Geological Survey, Reston, Virginia. Antarctic mapping operations. DPP 81-12853. $100,000.

Stump, Edmund. Arizona State University, Tempe, Arizona. Petrology and regional geology of early to Middle Paleozoic magmatic rocks, northern Victoria Land. DPP 80-19991. $39,789.

Unklesbay, A. G. American Geological Institute, Falls Church, Virginia. Travel of United States Scientists to Eleventh Congress of International Association for Quaternary Research, Moscow, USSR, (1-9 August 1982). EAR 82-06681. $5,000. ($18,000).

Webers, Gerald F. Macalester College, St. Paul, Minnesota. Geological investigations of the Ellsworth Mountains. DPP 80-20482. $34,150.

Zeller, Edward J. University of Kansas, Lawrence, Kansas. Resource and radioactivity survey in Antarctica by gammaray spectrometry. DPP 77-21504. $79,278.

Meteorology

Kelly, Thomas P. Department of Navy, Washington, D.C. Technical support for the LC-130 research-configured aircraft used in polar research programs. DPP 78-20114. $50,000.

Parish, Thomas R. University of Wyoming, Laramie, Wyoming. Research on surface winds of Antarctica. DPP 81-15976. $83,197.

Robinson, Elmer. Washington State University, Pullman, Washington. Air chemistry and meteorology in Antarctica. DPP 81-17488. $47,396.

Robinson, Elmer. Washington State University, Pullman, Washington. Air chemistry monitoring at Palmer Station. DPP 80-05797. $149,690.

Wendler, Gerd. University of Alaska, Fairbanks, Alaska. Katabatic winds in Antarctica. DPP 81-00161. $70,446.

Ocean sciences

Ackley, Stephen F. Department of the Army, Hanover, New Hampshire. Air-sea interaction and sea ice studies during the US-USSR Weddell polynya expedition. DPP 80-06922. $111,731.

Anderson, John B. Rice University, Houston, Texas. Marine geology of the antarctic continental margin. DPP 81-16623. $68,268.

Corliss, Bruce H. Woods Hole Oceanographic Institute, Woods Hole, Massachusetts. Quaternary thermohaline circulation in the southern ocean. DPP 80-20479. $59,000.

Gordon, Arnold L. Columbia University, Palisades, New York. US-USSR Weddell polynya expedition. DPP 80-05765. $24,608.

Gordon, Louis I. Oregon State University, Corvallis, Oregon. Winter nutrient cycling in the Weddell Sea. DPP 82-03529. $89,400.

Kellogg, Thomas B. University of Maine, Orono, Maine. Sediments deposited by marine-based ice sheets during the last glacial maximum. DPP 80-20000. $44,102. ($74,102).

Sclater, John G. Massachusetts Institute of Technology, Cambridge, Massachusetts. Tectonics of the southern ocean. DPP 81-17402. $119,653.

Support and services

Costello, John D. Department of Transportation, Washington, D.C. Services of USCG icebreakers, 1981-1982. DPP 80-24892. $75,825.

NSF photo by Russ Kinne.

Four USARP personnel climb icy slopes near McMurdo Station during the survival school. All field personnel participate in the survival school taught by U. S. and New Zealand experts in climbing and cold weather survival.

(Continued on back cover.)

Weather at U.S. stations

Feature	February 1982				March 1982				April 1982			
	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole
Average temperature (°C)	- 24.1	- 2.8	-30.9	-56.9	- 25.9	- 5.1	-25.3	- 60.6	-28.6	- 9.7	-35.2	- 58
Temperature maximum (°C) (date)	- 6.7 (21)	3.8 (18)	-14.1 (3)	-38.9 (7)	- 6.7 (10)	4.8 (5)	-11.0 (29)	- 39.3 (4)	-13.8 (5)	0.1 (23)	-13.2 (10)	-34.3 (21)
Temperature minimum (°C) (date)	- 37.8 (27)	-12.9 (31)	-41.8 (31)	-78.1 (26)	- 43.8 (21)	13.0 (2)	-42.0 (22)	- 82.8 (23)	-43.1 (19)	-19.3 (15,20)	-51.8 (31)	-73.9 (2)
Average station pressure (mb)	987.5	988.8	858.2	675.9	982.7	998.9	866.1	671.9	990.5	988.1	860.3	678.3
Pressure maximum (mb) (date)	1006.4 (25)	1008.8 (4)	877.6 (20)	688.0 (17,18)	998.5 (11)	1016.5 (14)	879.5 (8)	691.5 (9)	1023.9 (15)	1012.5 (6)	878.8 (15)	693.4 (15)
Pressure minimum (mb) (date)	958.5 (4)	967.2 (27,30)	833.9 (5)	658.6 (7)	960.7 (25)	975.2 (1)	847.0 (30)	648.8 (21)	965.1 (27)	959.5 (19)	839.2 (20)	660.5 (1)
Snowfall (mm)	218.4		749.3	Trace	274.3		1,143	Trace	181.6		125.7	Trace
Prevailing wind direction	065°		190°	045°	100°		230°	045°	050°		200°	045°
Average wind (m/sec)	4.5	4.8	7.7	5.4	4.6	3.6	5.7	4.1	3.2	5.4	4.6	5.7
Fastest wind (m/sec) (date)	25.9 (10) 130°	31.4 (1)	21.5 (29) 270°	21.6 (7) 360°	31.3 (10) 180°	33.5 (24)	22.4 (29) 260°	14.4 (3) 360°	24.6 (5) 060°	35.8	19.5 (7) 250°	19.6 (21) 270°
Average sky cover	5.6	8.6	5.3	2.1	6.9	8/10	5.2	4.3	4.1	8.2/10	3.4	2.5
Number clear days	4	0	9.75	23.3	0	1.2	13	17.4	10	2.4	18.25	23.1
Number partly cloudy days	12	11.5	25	4.9	4	12.7	.5	2.1	11	11	.25	2.2
Number cloudy days	15	19.5	21	2.8	26	17.1	16.5	10.5	10	17.6	12.5	5.7
Number days with visibility less than 0.4 km.	0	--	13.5	2.8	1.5	--	18.75	0	0	--	17.75	6.8

Prepared from information received by teletype from the stations. Locations: McMurdo 77°51'S 166°40'E, Palmer 64°46'S 64°3'W, Siple 75°55'S 83°55'W, Amundsen-Scott South Pole 90°S. Elevations: McMurdo sea level, Palmer sea level, Siple 1054 meters, Amundsen-Scott South Pole 2835 meters. For prior data and daily logs, contact National Climate Center, Asheville, North Carolina 28801.

Weather at U.S. stations

Feature	May 1982				June 1982				July 1982			
	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole
Average temperature (°C)	- 9.4	- 0.5	-19.7	-41.2	-20.9	- 0.8	-27.9	-54.8	-24.2	- 3.1	-33.8	-54.8
Temperature maximum (°C) (date)	0.6 (4)	4.0 (10,11)	- 4.3 (4)	-25.7 (2)	-12.3 (2)	6.0 (16)	-14.8 (24)	-39.0 (19)	- 7.1 (17)	4.0 (28)	-21.8 (17)	-34.3 (20)
Temperature minimum (°C) (date)	-21.1 (28)	-7.0 (19)	-30.6 (27)	-55.2 (28)	-33.6 (26)	- 9.5 (14)	-40.7 (14)	-68.5 (15)	-37.9 (11)	-11.2 (23)	-47.8 (25)	-75.1 (8)
Average station pressure (mb)	987.9	983.2	862.2	683.6	978.2	978.7	856.9	674.3	981.5	980.3	849.5	675.9
Pressure maximum (mb) (date)	995.4 (5,12)	997.1 (16)	870.9 (11)	693.8 (3)	997.5 (22)	1000.4 (2)	874.2 (19)	689.8 (19)	992.6 (4)	1005.5 (30)	864.4 (15)	694.1 (18)
Pressure minimum (mb) (date)	997.5 (19)	958.2 (19)	852.4 (21,22)	675.5 (24)	963.8 (26)	346.9 (3)	842.9 (4)	658.5 (26)	955.5 (10)	960.0 (11)	826.3 (10)	654.1 (10)
Snowfall (mm)	134.6		20.3	Trace	223.5		152.4	Trace	270		447.0	Trace
Prevailing wind direction	110°	020°	170°	045°	080°	360°	180°	360°	070°		180°	045°
Average wind (m/sec)	4.0	4.2	3.5	3.2	4.9	5.9	4.7	3.8	4.8	6.7	6.0	5.5
Fastest wind (m/sec) (date)	8.9 (10) 170°	29.1 (26) 60°	15.6 (11) 170°	14.4 (1) 360°	29.5 (16) 160°	27.3 (11) 075°	15.2* (3) 150°	13.4 (26) 360°	25 (18) 060°	32.9 (6) --	19.7 (28) 150°	17.5 (30) 360°
Average sky cover	8.1	8.4	6.0	4.3	7.0	9.2/10	5.5	7.5	7.9	9.1/10	3.0	4.4
Number clear days	1	1.5	6.2	15.7	0	0	5.5	6.7	4	0	10.75	15.9
Number partly cloudy days	3	8.3	7.6	2.0	7	7.8	4.5	5.0	3	7.7	.25	7.2
Number cloudy days	24	18.2	13.8	9.8	24	23.2	21	1.6	23	22.3	19	6.9
Number days with visibility less than 0.4 km.	0	--	6.1	0.2	1.3	--	9	0.4	1	--	11.75	0.5

Prepared from information received by teletype from the stations. Locations: McMurdo 77°51'S 166°40'E, Palmer 64°46'S 64°3'W, Siple 75°55'S 83°55'W, Amundsen-Scott South Pole 90°S. Elevations: McMurdo sea level, Palmer sea level, Siple 1054 meters, Amundsen-Scott South Pole 2835 meters. For prior data and daily logs, contact National Climate Center, Asheville, North Carolina 28801.

* Also on 19 March from 140°.

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(*Continued from page 21.*)

Gray, Rodney E. ITT Antarctic Services, Inc., Paramus, New Jersey. Support of the United States Antarctic Research Program. DPP 80-03801. $4,413,000.

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Laney, Jack. San Diego Hall of Science, San Diego, California. Support for 16mm and Omnimax films "Portrait of Antarctica". DPP 81-18214. Logistic support only.

Langway, Chester, C. State University of New York, Buffalo, New York. Operation of the central ice core storage facility and information exchange. DPP 75-08512. $13,529. ($65,327).

Pearigen, Jare M. Department of Defense, Washington, D.C. Logistic support for the U.S. program in Antarctica. DPP 76-10886. $22,137,000.

Pearigen, Jare M. Department of Defense, Washington, D.C. Nose landing gear strut assemblies for LC-130 aircraft. DPP 76-10886. $140,000.

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antarctic journal OF THE UNITED STATES

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25th anniversary of the International Geophysical Year

The International Geophysical Year (1957-58) brought together from 67 countries approximately 25,000 scientists, working at 2,500 stations around the world. From their investigations of the Earth's environment the world gained a large, coordinated data base on geomagnetism, the ionosphere, aurora, and cosmic rays. The first 24-hour watches of solar flares, sunspots, and other solar phenomena were conducted. Coordinated programs in seismology, gravity, geodesy, and oceanography improved understanding of the Earth and oceans, and the voluntary sharing of data through the World Data Center system was initiated.

The International Geophysical Year (IGY) also opened the way for research in two remote regions—space and the Antarctic. In 1954 the Comité Spécial de l'Année Géophysique Internationale, created by the International Council of Scientific Unions to plan the global science program, called the Antarctic "a region of almost unparalleled interest in the fields of geophysics and geography" and pointed out how little was known about the continent. When the antarctic portion of the IGY began, 12 nations were participating, and 55 stations were established around the continent and on subantarctic islands. Nine major scientific programs were planned for Antarctica: the aurora, cosmic rays, geomagnetism, glaciology, gravity, ionospheric physics, meteorology, seismology, and an international weather center (Antarctic Weather Central.) Along with these programs there was oceanography, biology, and medical sciences.

The success of cooperative efforts by the world's scientists during the IGY was dramatically demonstrated in Antarctica. The participating nations established stations in all areas of the continent and scientific personnel and information were exchanged openly through such programs as Antarctic Weather Central. In 1981 at the Eleventh Antarctic Treaty Consultative Meeting representatives recognized the importance of the IGY to current antarctic research programs as they commemorated the 20th anniversary of the Treaty's entry into force. They cited the IGY as the model for the Treaty's foundation of continued, peaceful cooperation and freedom of scientific investigation.

Albert Crary, deputy chief scientist of the U.S. IGY program and later chief scientist of the U.S. Antarctic Research Program, wrote the following article in recognition of the 25th anniversary of the IGY. Dr. Crary focuses on planning for the IGY and on how the IGY laid the foundation for today's antarctic research.

International Geophysical Year: Its evolution and U.S. participation

The idea for the Third International Polar Year (TIPY), later to become the International Geophysical Year (IGY), was introduced in 1950, 5 years after the end of World War II. In those postwar years, the cold-war struggle between the communists and democracies at times erupted in bitter fighting along the boundaries of the two camps. Stalin, the leader of the Union of Soviet Socialist Republics (USSR), was anxious to have communist-controlled buffer states along his western boundaries and tightened his grip on the eastern European nations. In western Europe the United States leaders, through the European Recovery Plan, poured in huge sums of money to help rebuild these war-ravaged nations. In the far north a new military geography evolved, pitting Alaska, Canada, and Greenland against the USSR across the Arctic Ocean. The western group hastened to increase its polar proficiency with such arctic expeditions as "Nanook" and "Mukluk," routine U. S. Air Force polar flights from Alaskan bases, the installation of weather stations in northern Canada, and the construction of Greenland bases.

During this period U. S. attention also turned toward the south. In the austral summer of 1946-1947, the U.S. Navy carried out Operation Highjump, the largest array of ships, aircraft, and men ever assembled in Antarctica. Some 4,700 men supported by 13 ships and 25 aircraft conducted scientific investigations, trained and tested equipment under polar conditions, and studied the feasibility of establishing an airbase on ice. Approximately 60 percent of the antarctic coastline, including previously unseen areas, was photographed. A second U.S. Navy expedition in 1947-48, Operation Windmill, named by the press for its extensive use of helicopters to reach isolated areas, provided additional ground-control for Highjump photography.

Early planning

In 1948 the U.S. State Department made a formal appeal to Argentina, Australia, Chile, France, Great Britain, New Zealand, and Norway (the seven nations with ant-

NS 1.26:

arctic claims) to initiate discussions of the sovereignty problem. At the same time the State Department asked the National Academy of Sciences (NAS) to examine the possibilities of a coordinated program of antarctic research. Neither of these efforts came to fruition.* In 1950 when the USSR learned of these sovereignty discussions, the Soviet government made it clear that no territorial settlements should be made without USSR participation.

Among those serving on the 1948 NAS committee considering coordinated antarctic research was Lloyd Berkner. The idea of TIPY was introduced by Berkner, a tall, pipe-smoking scientist who had been a radio technician in the first Byrd Antarctic Expedition (1928-1930). After the Byrd Expedition he joined the Carnegie Institution of Washington (CIW) where much of the new and exciting work on the ionosphere was being done. From 1941 to 1946 Berkner served in the Navy, particularly in the development of radar, and later was appointed to head a committee that was evaluating the relative importance of weapon systems for the national military establishment. As a special assistant at the State Department in 1949, he directed work in the military assistance program for the North Atlantic Security Pact nations. Later he surveyed the State Department's responsibilities in international science.

Although Berkner later referred to his idea of TIPY as a spur-of-the-moment thought, it should not have been totally unexpected. Regardless of the origin of the idea, Berkner introduced it and steered it through its early years.

Berkner's proposal for TIPY was approved by the Commission on the Ionosphere at its July 1950 meeting. In August it was endorsed by the General Assembly of the Union Radio Scientifique Internationale (URSI) and in September by the Executive Committee of the International Astronomical Union. The third union sponsor of the Commission on the Ionosphere, the International Union of Geodesy and Geophysics (IUGG), endorsed TIPY at its General Assembly in September 1951. The next month at the meeting of the Executive Board of the International Council of Scientific Unions (ICSU) the three union presidents confirmed their endorsements of TIPY. ICSU then authorized its Bureau to form a special committee. In September 1952 the ICSU's executive board approved the Bureau's membership nominations, welcomed the International Geographical Union and the World Meteorological Organization to the program, and agreed with the English geophysicist Sidney Chapman's suggestion that the project be worldwide to provide needed data for the equatorial regions and the Southern Hemisphere. Hence TIPY became the International Geophysical Year (IGY) and the committee became Comité Spécial de l'Année Géophysique Internationale (CSAGI).

An important ad hoc meeting of a few CSAGI members, including Berkner, took place in Brussels in October 1952. With E. Herbays of URSI acting as Secretary pro tem, the group drafted letters to the nations. Each nation was requested to form a national committee and estimate the types and size of IGY programs that each expected to carry out. These letters also called attention to the convening of the first CSAGI meeting in June 1953 in Brussels.

With help from Wallace Atwood of NAS and an ad hoc American Geophysical Union committee, Berkner lost no time in getting the U.S. National Committee for the IGY (USNC) organized. The original 20 members included 15 from Federal agencies and the CIW and reflected the broad nature of the programs. Joseph Kaplan, University of California auroral physicist and Air Force consultant, was appointed chairman. During two meetings in March and May 1953, the USNC put together a U.S. IGY program focused on upper atmosphere physics and meteorology. The antarctic program included a coastal station and two in the interior, one of the latter at the geographic South Pole.

For the CSAGI meeting in Brussels 22 members and observers (including three from the U.S.) from 12 nations were present. It is safe to say that never again was such a small delegation present for such an important meeting. After Chapman was elected President, 11 discipline groups were formed and a combined program put together from the 26 various national and union programs. Despite the necessary overlap of personnel in these groups, this program, with one revision by the participating nations, easily could have served as the final IGY plan.

National Science Foundation and the IGY

The financing of the U.S. IGY program was debated in the USNC meetings, but of all possibilities only a single congressional budget seemed satisfactory. By the end of 1953 the National Science Foundation (NSF), a small independent agency created by a 1950 Act of Congress (the same year TIPY was proposed), appeared to be the logical choice. The NSF budget for fiscal 1954 was about $8 million principally for support of research and science education at universities. NSF Director Alan Waterman, an astute science administrator, had followed the IGY plans closely. In all probability, the letter from NAS to NSF in November, asking NSF to consider funding the IGY program, had his prior approval.

To get the IGY on the road, Waterman had three tasks in early 1954. First, he had to get the concurrence of the Bureau of the Budget (BOB) for NSF to handle the program. Second, he required an acceptable budget from the USNC. And third, President Eisenhower's endorsement of the IGY was needed to encourage congressional support and secure antarctic logistics.

After an agreement with BOB was reached, BOB cleared the NSF role in the IGY with other involved agencies. The BOB also asked for estimates of antarctic expe-

Editor: Winifred Reuning

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* The Academy did, however, publish *Antarctic Research: Elements of a Coordinated Program* in May 1949.

U. S. Navy photo (XAM-50431-12-64) by James M. Long.

Alan T. Waterman (center) was director of the National Science Foundation during the IGY. In this photograph he talks with Vice Admiral John Bush from the British Embassy in Washington, D. C., and John Green from Great Britain in the wardroom at McMurdo Station during a 1964 tour of Antarctica.

ditionary costs. The Navy believed that $10 million would be needed for an austere expedition and up to $60 million for a full scale one. But the Navy emphasized that these expeditions could not be carried out without additional appropriations from Congress.

The responsibility for preparing the U.S. IGY budget was passed on to the new IGY staff that had taken over from Atwood, who had administered the program from the NAS international office. From the National Bureau of Standards Hugh Odishaw, whose adroit handling of the myraid IGY budget and administrative problems earned him the title "Mr. IGY," was chosen to be the head of the IGY office. With Odishaw's direction the budget for the IGY was assembled from the disparate discipline groups: $13 million, a one-shot affair as Waterman emphasized to BOB. The BOB decided to ask for $2.5 million in a supplemental fiscal 1955 budget for advance equipment, and the remaining $10.5 million in the regular NSF fiscal 1956 budget.

President Eisenhower's endorsement required many negotiations with the President's staff and all the help that Waterman and the BOB could muster. Timed for the budget's arrival in Congress in early June 1954, the endorsement was a tremendous boost for the IGY. Although no mention was made of the antarctic logistics, the USNC henceforth assumed such costs would not be from the IGY budget.

For many of these negotiations and others to follow, Waterman and the IGY found an ally in a newly elected National Science Board (NSB) member—Laurence Gould. Officially Gould had agreed to head the Antarctic IGY Committee. As the respected President of a midwestern college, a member of the Ford Foundation, and the former chief scientist of the first Byrd Antarctic Expedition, he opened doors in both executive and legislative Washington with his forthright, down-to-earth style. Though a geologist whose science was not encompassed in the IGY, he nevertheless became the program's most valuable trouble-shooter.

Expanding IGY plans

The second CSAGI meeting in Rome in mid-1954 was to be the final review of the IGY program, but three events boosted the program's coverage and fortunes far beyond the anticipation of the IGY planners. First was the presence of a USSR delegation at Rome. Only with the death of Stalin in 1953 were the rules for USSR participation in international programs relaxed. Although he presented no official program, the head of the USSR delegation stressed the need for earth sciences in IGY.

The second factor was the interest in the regional antarctic committee chaired by Berkner. The committee examined total coverage and called attention to regions where no stations had been established. However, the open invitation for IGY nations to establish stations in territories already claimed, together with the participation of the USSR in the IGY, sent chills down the backs of foreign ministries. In the United States the polar veteran George Dufek was recalled from retirement to head the Operations Coordinating Board's (OCB) antarctic subcommittee and to plan an expedition to examine potential station sites during the 1954-1955 austral summer.

The third surprise development at the meeting in Rome was in the resolutions of the rocket program—an innocuous paragraph encouraging the logical extension of rockets to earth-circling satellites. This was the work of S. Fred Singer with aid from the Berkner who helped him steer appropriate resolutions through URSI, IUGG, and finally CSAGI in the summer of 1954.

The remainder of Waterman's "one-shot" IGY budget was duly sent through to the BOB in late 1954 along with the regular NSF budget, but pressure for an additional supplement could not be contained. Merle Tuve, respected division head at the Carnegie Institution, was the first to break the near-monopoly of the atmospheric sciences in the IGY by pleading at the November 1954 USNC meeting for support of new developments in seismology and gravity. He was asked to form an ad hoc group and prepare a budget, which he proceeded to do at once. He enlisted such project-rich and money-poor scientists as Maurice Ewing and George Woollard.

With Tuve's figures and a few other items, the USNC submitted a supplemental budget of $2.593 million to NSF. Congress had cut $0.5 million from the earlier $2.5 million request with the comment that, if the NSF Director thought it important enough, he could take it from the NSF budget. The NSB, already miffed at USNC insistence on the $0.5 million, expressed extreme concern over the latest addition but, after a long debate, left the decision to the Director. Perhaps seeing the handwriting on the wall, Waterman did not submit this supplement request. The $2.593 million grew rapidly and eventually came back to the NSB as $27.559 million which included satellites and extra stations. The NSB voted a sum not to exceed $29 million.

The need for an antarctic conference became evident after the Rome meeting, and in early 1955 Berkner wrote the CSAGI secretariat suggesting a meeting in Paris with G. R. Laclavere (Secretary General, IUGG) as convener. At this conference the first outline was given of the USSR antarctic program; they had accepted the invitation to fill the station gap in the coastal region of East Antarctica and also announced plans for two interior stations. The U.S. noted that it would add two additional coastal stations along the Weddell Sea and in East Antarctica, a decision dictated more by national interests than IGY requirements.

Another important item at the Paris conference came about during discussions of the U.S. Weather Central, which would assemble antarctic meteorological data. Harry Wexler, a meteorologist of great energy and enthusiasm, had agreed in April 1955 to be chief scientist for the U.S. antarctic program. When Wexler's Weather Central item was accepted, the USSR delegate asked for major USSR participation. While agreeing with the participation but not the numbers, Wexler also proposed that the U.S. send a meteorologist to the main USSR station. The USSR delegate said this was another matter. Wexler persisted, and in the end the USSR agreed to the exchange. This was fortunate as there were many in the U.S. who were uneasy at the prospect of USSR personnel at U.S. stations, and the quid pro quo arrangement made it more acceptable. The personnel exchange between the U.S. and the USSR has continued through the years.

The IGY and Operation Deep Freeze

In 1955 Albert Crary of the Air Force Cambridge Research Center joined the IGY circles as head of the Glaciological Headquarters Office, the operating arm of the IGY glaciology panel with its major program focusing on antarctic oversnow traverses. By late 1955 Crary had been chosen as deputy chief scientist to assist Wexler. A confusing factor in their planning at this point was the existence of two discrete U.S. programs: the IGY and the non-IGY. The latter, represented by the Navy's Task Force 43, comprised the national interests in the broad categories of exploration and mapping under Paul Siple, chief scientist of the task force. Neither Wexler nor Crary was able to learn any details of these non-IGY items.

In the 1955-1956 austral summer Dufek led the Deep Freeze I expedition to construct the Little America Station and the McMurdo Naval Air Facility and get a start on the two interior stations in Marie Byrd Land and at the South Pole. Deep Freeze I was an all-Navy operation of much importance. In December after the Seabees had built an ice runway at McMurdo, Navy pilots flew two R5D Skymaster and two P2V Neptune planes from New Zealand to McMurdo in the first flights to Antarctica from outside lands. In January they flew these planes on many exploratory missions from McMurdo to the interior, across East Antarctica to the coastal areas, and across West Antarctica to the Weddell Sea. But as significant as these flights were to U.S. interests, Dufek's command failed to find a safe route from Little America to the Byrd Station site and, much to the disappointment of Admiral Byrd and Paul Siple, made no attempt to land a plane at the South Pole.

In January 1956 a radical change took place in Task Force 43 affairs. The Navy 1957-1958 budget was cut drastically, and all major non-IGY programs were dropped. An explanation for this development is given in Admiral Dufek's book *Operation Deepfreeze*. The Navy had budgeted about $58 million for the 1957-1958 expedition. Admiral Donald B. Duncan, Vice Chief of Naval Operations, told President Eisenhower that the Navy could not afford to spend that much money from its own budget. The President told him to take $22 million and do the best he could.

For Deep Freeze II, Dufek continually reminded his men that their sole purpose in the Antarctic was to support the IGY. The Navy obtained from the Army its best Greenland oversnow trail team, and a safe trail from Little America to Byrd Station, including 7 miles through crevasses, was blazed in time for the cargo trains to haul construction units to Byrd. The U.S. Air Force, with its C-124 Globemaster cargo planes, provided all airdrops for the South Pole Station and assisted at Byrd Station with fuel drops. Both stations were constructed in early 1957.

Officially the IGY started 1 July 1957 and ended 31 December 1958. At the first CSAGI meeting in 1953, 22 nations were in the IGY; at the time the field operations started there were 67. Over 25,000 scientists and technicians were involved, with the total expenditure over $2 billion. In the Antarctic, 12 nations participated at a total of 55 stations, including subantarctic islands and summer stations. The U.S. had five IGY stations—Little America, Byrd, Amundsen-Scott (Pole), Ellsworth, and Wilkes; one IGY station operated jointly with New Zealand—Hallett; and the Naval Air Facility at McMurdo. The investigations were carried out on the aurora, cosmic rays, geomagnetism, glaciology, gravi-

Rear Admiral George Dufek (right) headed the Operations Coordinating Board's antarctic subcommittee and planned a 1954-55 expedition to Antarctica. During the IGY he led the Navy's Operation Deep Freeze II in support of U. S. scientists in Antarctica. In this 1955 photograph he is awarded the stars of a Rear Admiral by Admiral R. B. Carney (left) in recognition of his achievements in Antarctica. Rear Admiral Richard E. Byrd (center) looks on.

U. S. Navy photo.

ty, ionosphere physics, meteorology, oceanography, seismology, terrestrial biology, and medical science.

The U.S. IGY funds expended in Antarctica (salaries and instruments) were about $4.6 million, but this figure does not include shipboard oceanography, the meteorology at three IGY stations and McMurdo Naval Air Facility, the biology and medical sciences, and the deep drill holes at Byrd and Little America Station. All of these were funded by offices in the Navy, Army, or Air Force. Nor does it include either special funds obtained from the Department of Defense for such items as the oversnow traverse vehicles or the salaries that were contributed by other agencies for many of the IGY scientists. The total science budget, still excluding the main logistics items such as ships and aircraft, was about $10 million.

U. S. Navy photo

A small bulldozer serves as a taxi between the airstrip and Amundsen-Scott South Pole Station during the 1959-60 austral summer. South Pole Station at the geographic south pole was established by the United States in 1956 for the International Geophysical Year and has been occupied continuously since then. In 1975 the station was rebuilt as a geodesic dome 50 meters wide and 16 meters high that, with 14- by 24-meter steel archways, covers modular buildings, fuel bladders, and equipment.

Post-IGY planning and activities

In late 1956, even as the first IGY contingent was enroute to the Antarctic, post-IGY possibilities were being discussed. At the USNC meeting in early December, Berkner raised the issue of extending IGY antarctic activities an additional year. A resolution was approved to add the possibility of a post-IGY year to the CSAGI agenda at their June 1957 meeting. CSAGI referred the possible extension to ICSU, which authorized an ad hoc meeting of national delegates in September. According to Wexler, the U.S. delegate to this meeting, there were heated debates the first day, with Great Britain leading the opponents of the extension. On the second day the USSR delegate arrived and announced that his country intended to continue all present and planned stations; all opposition was dropped. The Stockholm resolutions made it clear that the Special Committee for Antarctic Research (SCAR) that was being recommended to ICSU was not for an extension of IGY. ICSU approved the formation of SCAR, which held its first two meetings in 1958.

The official U.S. policy for post-IGY operations in Antarctica was released in June 1957: activities would be on a minimal basis consistent with national interests. The Operations Coordinating Board (OCB) antarctic subcommittee interpreted this as limiting the 1959 operations to four stations: McMurdo, Pole, Byrd, and Hallett. Wexler and several others wanted Little America Station to continue because of the long period of scientific observations in that area, but Dufek was adamantly opposed. The risks involved in unloading supplies from ship to barrier were too great. Glenn Dyer, the Commerce Department representative on the OCB antarctic subcommittee, headed a group to prepare the overall budget for 1959 activities. IGY personnel contested this austere budget without success.

Despite budget pressures for the 1959 science activities, it was not until January 1958 that Waterman officially announced the NSF continuing antarctic program, which became the United States Antarctic Research Program (USARP). And it was 2 years later before an Executive Order, Circular A-51, was approved. This circular sets forth policies governing the antarctic activities, with NSF having the principal coordination and management role in science. By that time, the antarctic staff under Thomas O. Jones included many IGY antarctic veterans: Albert P. Crary, Henry S. Francis, Kendall N. Moulton, Philip M. Smith, and George R. Toney. Circular A-51 also ended the long and active role of the Operations Coordinating Board antarctic subcommittee.

The Committee on Polar Research, set up by the National Academy of Sciences with Gould as chairman, held several meetings in 1958. Four panels were formed: earth crust and core, biological and medical sciences, heat and water, and upper atmosphere. High priority recommendations to NSF were a complete biological laboratory at McMurdo and an oceanographic vessel. In 1959, the committee began a thorough study of the present status and predicted future trend of sciences, resulting in the publication in 1961 of the two-volume *Science in Antarctica.*

The IGY period 25 years ago initiated sustained observations in the polar regions, space, and elsewhere. These years also heralded major U.S. advances in science and technology in the next decade. However, it was also 25 years ago when the first earth-circling satellite the USSR *Sputnik* was launched. Though a part of the IGY,

U. S. Navy photo.

Lcdr. T. N. Thompson, the U. S. Navy officer-in-charge at Little America V, shakes hands with Albert P. Crary, deputy chief scientist of the U. S. International Geophysical Year expedition, on 13 February 1958. Dr. Crary has just returned from a 113-day, 2,092-kilometer traverse that he led.

Sputnik undoubtedly had a more direct bearing on the U.S. advances in science and technology than all the rest of the IGY.

It remained for the State Department to climax the events of the IGY years. In May 1958, President Eisenhower announced that the U.S. government had invited the nations involved in Antarctica to a conference to discuss the formation of a treaty. A long series of meetings in 1958 and 1959 culminated in December 1959 with one of the most significant events in antarctic history the signing of the Antarctic Treaty by 12 nations. Though independent of IGY, the willingness of the nations to enter into the Treaty exemplified the spirit of international cooperation that characterized the International Geophysical Year.

—Albert P. Crary, Bethesda, Maryland.

Department of State issues an environmental impact statement on mineral resources

The National Environmental Policy Act of 1969 requires government agencies to assess the environmental impact of "major Federal actions significantly affecting the quality of the human environment." In conformance with this act five U.S. antarctic environmental impact statements have been issued. (A list follows this article.) Three of them cover specific activities in the region: two large research projects (since completed) and the whole of the United States Antarctic Research Program. The fourth and fifth statements, issued by the Department of State, concern future activities. Of these, one published in 1978 discussed possible approaches to negotiation of an international regime for marine living resources. It helped guide U.S. participation in the formulation and signing of the Convention on the Conservation of Antarctic Marine Living Resources, which entered into force in 1982 (*Antarctic Journal*, December 1980 and March 1982).

The fifth statement was issued in August of this year: It is the *Final Environmental Impact Statement on the Negotiation of an International Regime for Antarctic Mineral Resources*. The document acknowledges the growing interest in potential antarctic mineral resources and the current absence of a legal basis for commercial mineral activities. "Some experts believe exploitation of possible offshore hydrocarbon reservoirs may be feasible within the next few decades," it states, "although exploitation of possible onshore minerals is considered more remote. Nevertheless, exploration could occur now and this raises not only environmental issues but issues bearing directly upon the legal and political status of Antarctica."

The report considers seven actions ranging from no action to negotiation of a permanent moratorium on mineral resource activities in the Antarctic. The proposed Federal action, however, is to negotiate a regime covering both exploration for and exploitation of minerals on the continent and offshore. This action "is designed to protect the full range of United States interests, including nondiscriminatory access for United States nationals and firms to engage in any permitted mineral resource activities. It would offer a stable international basis for necessary economic, as well as environmental, decisions." A cornerstone of the U.S. position in the negotiations is to allow minerals exploration and exploitation only if environmentally acceptable on the basis of adequate scientific information.

Upon formulation of a draft report in 1981, the Department of State solicited comments from government agencies and offices, environmental and legal organizations, and individuals. The draft also was announced in the *Federal Register*. Ten Federal agencies, three environmental organizations, and three private corporations and individuals provided written comments. These comments were incorporated into a final statement, also made available for public comment in mid-1982.

The Department of State published the 250-page final report in August 1982. The report describes the proposed action and the alternatives, discusses existing international agreements, describes the existing environment and the environmental consequences of mineral exploration and exploitation, and discusses the environmental impact of the proposed action and the alternatives. Appendixes contain a more detailed description of the environment, a copy of the Antarctic Treaty and selected recommendations, copies of comment letters and responses, and a list of organizations and persons from whom comments were solicited.

The "record of decision," making the statement a binding document for Federal decisions, appeared in the 8 November 1982 *Federal Register*, pages 50598-50599.

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Edward A. Knapp appointed seventh NSF director

On 3 November 1982 Edward A. Knapp became the seventh director of the National Science Foundation (NSF), after President Reagan's announcement of Dr. Knapp's recess appointment on 2 November. Dr. Knapp succeeds John B. Slaughter, who had served as Director of the Foundation since December 1980. Dr. Slaughter has assumed the post of Chancellor of the University of Maryland in College Park, Maryland.

A physicist, Dr. Knapp joined NSF on 16 September 1982 as assistant director for Mathematical and Physical Sciences. Before coming to NSF he was head of the Accelerator Technology Division at Los Alamos National Laboratory in New Mexico. This division specializes in particle-accelerator research and development leading to instrumentation for a variety of basic and applied research projects. Dr. Knapp began his work at the Los Alamos Laboratory in 1958 and over the years worked on various projects, including the design of the accelerator structures for the laboratory's half-mile-long linear proton accelerator, the Los Alamos Meson Physics Facility. These systems, also used by industry, led to the development of a compact electron accelerator now used by more than 500 institutions for radiation therapy of cancer. During a 1972 sabbatical, Dr. Knapp worked at the European Organization for Nuclear Research in Switzerland, where he helped to design a new proton accelerator for that facility and to develop a collaborative high-energy physics program between Los Alamos and the European group.

NSF photo.

In November 1982 Edward A. Knapp became the National Science Foundation's seventh director. He succeeds John B. Slaughter, director from 1980 to 1982.

Dr. Knapp received his A. B. degree in physics (1954) from Pomona College in Claremont, California, and his Ph.D degree in high-energy physics (1958) from the University of California at Berkeley. He is a fellow of the American Physical Society, a member of many scientific and technical orgnizations, and the author or coauthor of approximately 100 scientific papers.

Southern Ocean Atlas published

"The enormous accumulative set of hydrographic data obtained during the last hundred years," Arnold Gordon writes in his preface to Columbia University's new *Southern Ocean Atlas,* "fills data banks." Dr. Gordon and Ted N. Baker of Columbia's Lamont-Doherty Geological Observatory, and Eugene J. Molinelli of Planning Systems, Inc., McLean, Virginia, have carefully selected 6,313 hydrographic stations—most of them south of 30°S—and used these data to create a 248-plate atlas of physical properties of the southern ocean. The plates and accompanying texts show horizontal distributions and vertical sections of potential temperature, salinity, density, oxygen, silicate, phosphate, and nitrate.

The atlas culminates a truly international undertaking, drawing on data collected by 71 ships sent out by 15 nations. The United States provided 2,917 stations—46 percent of the total—with *Eltanin* accounting for slightly over half the U.S. contribution. Just three antarctic veterans—*Eltanin* (U.S.A), *Discovery II* (U.K.), and *Ob* (U.S.S.R.)—contributed 50.4 percent of the stations.

Published by the Columbia University Press in 1982, the atlas consists of two sections: interpretive contouring of the data in the traditional form of maps, sections, and bivariate scatter diagrams and, for those wary of interpretive contours, a grid-point data set contoured by a computerized algorithm.

The National Science Foundation provided partial support for publication of the atlas and supported much of the U.S. shipboard data collection. A few copies are still available to working scientists for $30 from Columbia University Press in New York.

For each section of the atlas, data sets are available from the National Oceanographic Data Center (NODC). Hydrographic stations for the interpretative section of the atlas were selected on the basis of quality, uniformity of geographic distribution, and depth coverage. For this data set (the Atlas Data Set) 33,866 hydrographic stations south of 30°S in the NODC archive files were reviewed. All stations, except for USNS *Eltanin* stations which were reviewed separately and added later, were carefully screened; only 3,698 stations remained after the review. These stations along with 1,420 *Eltanin* stations and 1,195 stations from various other cruises comprise the 6,313 stations of the Atlas Data Set.

The second data set (the Grid-Point Data Set) was used to produce the objectively contoured map in the second section of the book. Based on the Atlas Data Set, a circumpolar grid between 30°S and 80°S was defined with cells that are 1 degree of latitude by 2 degrees of longitude. This data tape, which includes 181 points in the east-west direction and 51 points in the north-south direction, contains 9,231 records. Vertically, the grid is defined by 47 standard levels between 0 and 9,500 meters.

Both digital data sets are available on 9-track, 1600 BPI magnetic tapes for $110 each. Orders and requests for further information about the data sets and their tape formats should be directed to the National Oceanographic Data Center, NOAA/EDIS, D721, 2001 Wisconsin Avenue, N.W., Washington, D.C. 20235; telephone 202/634-7500. Please cite the NODC Accession No. 8200203, when ordering.

NSF photo by Kevin Schafer.

Mountains are reflected in saline Don Juan Pond in Wright Valley one of southern Victoria Land's ice-free valleys.

Scientists report rare meteorite found in Antarctica may be moon rock

Antarctic scientists have found what appears to be a new type of meteorite, that may be a fragment of moon rock. The finding has excited the scientific community because it lends credence to the idea that it is possible to find meteorites composed of material from objects in the solar system other than asteroids.

Meteorites are masses of stony or metallic material that penetrate the earth's atmosphere before plunging to earth. Scientists believe that most meteorites originate in the asteroid belt, a region of numerous minor planets with orbits between those of Mars and Jupiter.

Dr. William A. Cassidy, a University of Pittsburgh geologist who headed the group that found the meteorite, said it could be among the most significant scientific findings in the field of planetary sciences in recent years. "It's been suggested for years that fragments have been knocked off the moon by meteor impact," Dr. Cassidy said. "But this could be the first concrete evidence that such a process actually is occurring. In recent years we have found two meteorites that many scientists now believe are actual samples of the surface of Mars. If this latest sample is shown to come from the lunar surface, we have to begin thinking of the antarctic ice sheet as a place that collects and preserves not only fragments of asteroids but also fragments of other solar system bodies."

The meteorite was among the last of 378 found during the 1981-82 austral summer by a group of seven researchers Dr. Cassidy was leading in a region of ice fields known near the Allan Hills, about 140 miles northwest of McMurdo Station, principal U.S. scientific outpost in Antarctica. The group, funded by the National Science Foundation, was making a systematic search of the area last January when a member of the party, John Schutt, found the meteorite. It was of immediate special interest because of its light green outer crust (most meteorites are black). A more detailed report of their investigations will appear in the 1982 annual review issue of the *Antarctic Journal* to be distributed in early 1983.

"If this is a lunar sample, it will be in great demand as a specimen from the moon," Dr. Cassidy said. "On the other hand, if it is not a lunar sample it would have come from a body whose geologic history was quite similar to that of the moon."

Dr. Brian Mason, curator in the Smithsonian Institution's Department of Mineral Sciences in Washington, D.C., said that whether or not the meteorite proves to be a moon rock, the discovery is "a major scientific finding." Dr. Mason has examined a thin slice of the meteorite to determine its mineralogy and internal structure. He found the meteorite to be an anorthositic breccia composed primarily of the mineral plagioclase feldspar in a glassy matrix. He said some of the fragments resemble lunar rocks. The meteorite is about the size of a 2.54-centimeter sphere and weighs about 28 grams (one ounce). According to Dr. Mason, the light green color of its crust is due to its low iron content.

Two meteorites, previously found in the Allan Hills region, are believed by some scientists to have originated on Mars. There are only two other such meteorites known in this class, including one that was seen to fall in Shergotty, India, on 25 August 1865. These four meteorites have young crystallization ages of less than 1.3 billion years as compared to the 4.5-billion-year ages of other meteorites. They are igneous and more closely resemble terrestrial rocks than other igneous meteorite fragments.

The study of meteorites is of great scientific interest because some of them contain material relatively unchanged from conditions in the primordial cloud from which the solar system formed. They also can give scientists clues about the early evolution of the sun, complex primordial organic molecules, and the nature of asteroids. From specimens like these, scientists hope to get preliminary information on the surface materials of other planetary bodies including ones that man may visit in the future.

Meteorites found in Antarctica have a special quality not found in those discovered elsewhere. Because the ice and cold protect them from chemical reactions, contamination and erosion, the specimens give scientists clues that were denied them before. Meteorites found elsewhere have lost many of their pristine qualities because of contact with manmade and natural contaminants and weathering by exposure to the elements.

Antarctic meteorite samples arrive frozen at the National Aeronautics and Space Administration's Johnson Space Center in Houston where they are put into a freezer and handled like lunar samples. They are unpacked, photographed, and weighed under cold, sterile conditions, and accounts are written of each, following a visual examination. Slices are sent to investigators such as Dr. Mason for further and more intense study. The National Science Foundation, which funds and manages U.S. scientific activities in Antarctica, oversees subsequent allocations of samples from antarctic meteorites to qualified scientists in many countries.

The Meteorite Working Group, which is composed of 10 members from field teams, curation groups, and the scientific community, held a special meeting in December 1982 to consider requests for samples of the new meteorite. The group will distribute samples in such a way as to ensure that as many of the meteorite's chemical and physical characteristics as possible are determined before the 14th Lunar and Planetary Science Conference in March 1983.

—Ralph Kazarian, Office of Government and Public Programs, National Science Foundation.

Support contractor names new program director

At the end of August 1982 Robert A. Becker was named program director of Antarctic Services Inc. (ANS), the support contractor for the United States Antarctic Research Program. ANS Inc. operates South Pole, Palmer, and Siple Stations and R/V *Hero* and provides support at McMurdo Station, Williams Field, and elsewhere.

Mr. Becker joined the ANS Inc. parent company Federal Electric Corporation (FEC, a subsidiary of International Telephone and Telegraph Corporation) in 1959. Over the last 23 years he has held various technical and business management positions of increasing responsibility within FEC. Most recently he was responsible for technical operation and support for three U.S. Army contracts in the United States and Europe, coordination of the corporate headquarters operations and of field project support, and management of contract preparation and negotiations. Besides work with the U.S. Army, Mr. Becker has managed a technical contract for the National Aeronautics and Space Administration and a subcontract in support of the North Atlantic Treaty Organization satellite communication system in Europe. Mr. Becker received a degree in accounting from Seton Hall University in 1950.

Mr. Becker replaces Rodney E. Gray, who had been program director for ANS Inc. from 1980 until June 1982. The headquarters are at 621 Industrial Avenue, Paramus, New Jersey 07652. Mr. Becker and other company officials can be reached at 201/967-0123.

New place names identified

The following list provides antarctic place names as approved by the U.S. Board on Geographic Names from 1 October 1977 through 30 April 1982. Intended as a supplement to the 1981 volume of *Geographic Names of the Antarctic* (SN 038-000-00471-5:$13 from Government Printing Office, Washington, D.C. 20402), the toponyms are arranged alphabetically with specific elements first. Geographic coordinates have been determined from the most reliable sources.

These name decisions by the Board on Geographic Names were approved as recommended by its Advisory Committee on Antarctic Names. The names have been approved for use by U.S. government agencies. Their use by specialists and the public is highly recommended for the sake of accuracy and uniformity. Present members of the advisory committee are Walter R. Seelig, chairman (National Science Foundation), Alison Wilson (National Archives), Peter F. Bermel (U.S. Geological Survey), Luther W. Wheat (U.S. Navy), and Richard R. Randall (ex officio, Board on Geographic Names).

Research and staff support for the advisory committee is provided by the Toponymic Branch, Defense Mapping Agency Hydrographic/Topographic Center. Funding for research completed before 31 December 1981 was provided by National Science Foundation grant DPP 79-02112.

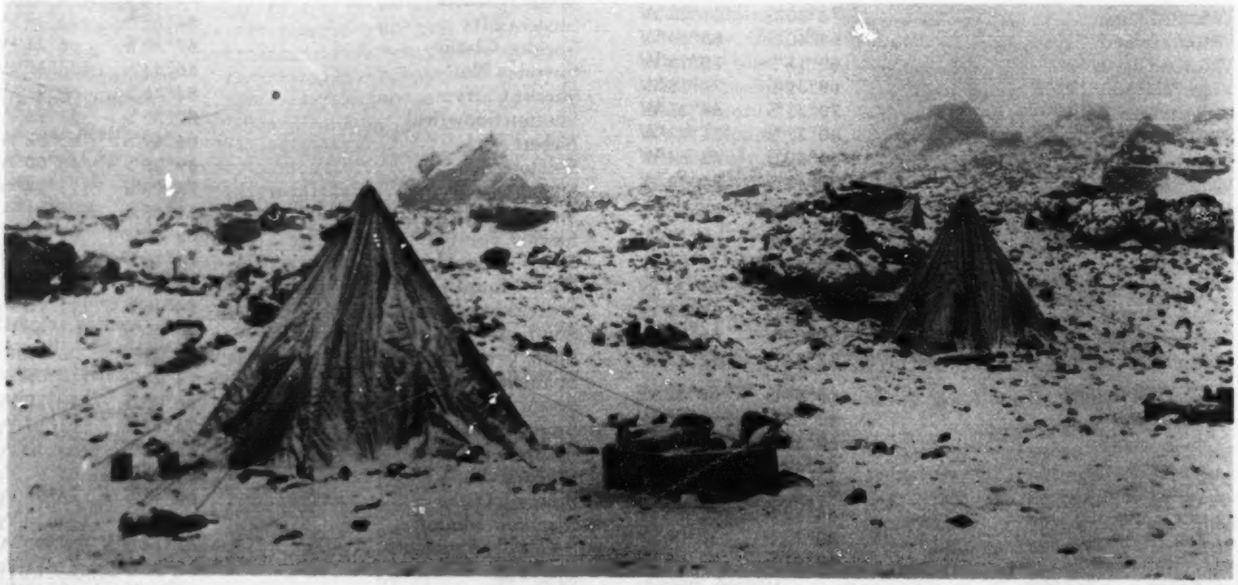
—Thomas Strenger, Defense Mapping Agency Hydrographic/Topographic Center, Toponymic Branch, Washington, D.C.

Abele Spur	83°13'S	51°05'W
Ablation Lake	70°49'S	68°26'W
Aquirre Passage	64°49'S	62°51'W
Alberts Glacier	66°52'S	64°50'W
Aldea Island	69°13'S	68°30'W
Allan, Mount	69°59'S	67°45'W
Alvaro Cove	64°51'S	63°01'W
Amherst, Mount	86°33'S	153°00'W
Analogue, Mount	85°49'S	138°08'W
Anvil Crag	62°12'S	58°29'W
Appalachia Nunataks	69°44'S	71°09'W
Arena Corner	69°51'S	68°02'W
Arenite Ridge	69°41'S	69°30'W
Arkell Cirque	80°41'S	24°08'W
Armbruster Rocks	73°57'S	116°48'W
Aronson Corner	80°29'S	20°56'W
Astudillo Glacier	64°53'S	62°51'W
Atkinson, Mount	78°39'S	85°30'W
Baines Nunatak	80°19'S	23°59'W
Barnes Bluff	74°46'S	110°19'W
Barrett Buttress	72°13'S	65°36'W
Bates Peak	69°35'S	72°55'W
Beagle Peak	69°36'S	71°45'W
Beche Blade	80°43'S	24°19'W
Beney, Mount	80°16'S	27°45'W
Bennett Spur	82°26'S	50°38'W
Bergan Castle	80°36'S	21°21'W
Bergen Nunataks	72°25'S	64°53'W
Bernhardi Heights	80°20'S	25°00'W
Beyl Head	74°05'S	116°31'W
Black Pass	67°40'S	67°34'W
Blanchard Hill	80°26'S	21°56'W
Bodziony, Mount	74°34'S	111°54'W
Bonney Bowl	80°21'S	25°35'W
Boreas Peak	69°38'S	68°20'W
Boschert Glacier	74°43'S	111°30'W
Bothy Bay	60°09'S	58°57'W
Bothy Lake	60°44'S	45°40'W
Bowen Cirque	80°42'S	23°27'W
Bowman Inlet	68°42'S	64°23'W
Boyd Escarpment	82°26'S	50°30'W
Braun, Mount	69°26'S	71°31'W

Brennan Inlet	74°28'S	116°35'W
Brennecke Nunataks	72°14'S	63°35'W
Britten Inlet	72°36'S	72°30'W
Brodie Peak	69°25'S	66°05'W
Burgess Ice Rise	70°23'S	73°21'W
Burkitt Nunatak	69°42'S	66°53'W
Burmester Dome	83°22'S	50°56'W
Burn Cliffs	70°06'S	69°52'W
Burro Peaks	62°26'S	59°47'W
Butterfly Knoll	80°21'S	28°09'W
Caninus, Nunataks	71°06'S	70°10'W
Care Heights	69°25'S	70°50'W
Carey Range	72°53'S	62°37'W
Carlson Buttress	82°35'S	52°27'W
Carlson Glacier	69°25'S	68°03'W
Casey Islands	64°44'S	64°16'W
Charlesworth Cliffs	80°14'S	25°18'W
Charpentier Pyramid	80°16'S	25°37'W
Chevreul Cliffs	80°32'S	20°36'W
Chinook Pass	69°29'S	68°33'W
Chisel Peak	67°40'S	67°42'W
Clarkson Cliffs	80°28'S	27°04'W
Clarsach Glacier	69°57'S	70°17'W
Clayton Ramparts	80°44'S	27°25'W
Clement Hill	62°13'S	58°58'W
Clemons Spur	82°31'S	51°13'W
Cockerell Peninsula	63°24'S	58°08'W
Coker Ice Rise	69°04'S	67°08'W
Colbert, Mount	86°12'S	153°05'W
Cooke Crags	83°10'S	50°43'W
Coral Ridge	74°35'S	163°25'W
Coulter Glacier	69°20'S	71°53'W
Couperin Bay	72°08'S	74°22'W
Coyer Point	74°24'S	113°13'W
Curran Bluff	68°13'S	65°02'W
Czamanske Ridge	82°35'S	52°42'W
Dewar, Mount	80°32'S	21°11'W
Davies Heights	62°11'S	58°56'W
Davis Ice Rise	74°56'S	110°18'W
Desko Mountains	69°37'S	72°30'W
Dietz Bluff	72°02'S	62°08'W
Dorchuck Glacier	74°44'S	113°56'W
Downs Nunatak	69°36'S	66°40'W
Dragons Back, The	80°23'S	28°33'W
Duffy Peak	71°45'S	70°40'W
Du Toit Mountains	72°28'S	62°11'W
Du Toit Nunataks	80°44'S	25°50'W
Eckman Bluff	74°47'S	110°22'W
Edwards Gap	71°15'S	70°20'W
Eisner Peak	68°50'S	65°45'W
Ellis Ridge	74°45'S	113°54'W
Emerald Nunatak	69°39'S	70°02'W
England Peak	82°37'S	52°49'W
Erlanger Spur	83°16'S	51°06'W
Erratic Valley	70°47'S	68°25'W
Eskola Cirque	80°43'S	23°49'W
Etchells, Mount	80°18'S	28°21'W
Express Island	62°27'S	59°59'W
Faulkner Nunatak	69°36'S	71°48'W
Fauré Inlet	72°37'S	70°48'W
Ferrer Rocks	64°42'S	62°48'W
Finlandia Foothills	69°56'S	70°09'W
Flatiron Valley	70°54'S	68°29'W
Flett Crags	80°39'S	23°35'W
Fogg Highland	72°45'S	60°50'W
Föhn Bastion	69°31'S	68°36'W
Ford Ice Piedmont	82°10'S	50°00'W
Forlidas Pond	82°27'S	51°21'W
Fournier Ridge	69°34'S	72°42'W
Franca Glacier	68°23'S	65°34'W
Franko Escarpment	83°02'S	49°00'W
Freshfield Nunatak	80°28'S	24°53'W
Frödin, Mount	64°50'S	62°50'W
Gabbro Crest	83°23'S	50°22'W
Gannon Nunataks	70°43'S	69°28'W
Garwood Point	74°14'S	110°36'W
Garzón Point	64°55'S	62°53'W
Gaudin Point	65°05'S	63°22'W
Geikie Nunatak	80°24'S	25°52'W
Genghis Hills	80°44'S	28°02'W
Geode Nunataks	69°50'S	70°08'W
Gerontius Glacier	69°31'S	70°34'W
Getman Ice Piedmont	68°06'S	64°57'W
Gilbert Glacier	70°00'S	71°00'W
Gilliamsen Peak	71°51'S	70°20'W
Glade Bay	73°58'S	115°15'W
Gneiss Lake	60°44'S	45°39'W
Goepfert Bluff	74°39'S	110°19'W
Golden Pass	69°23'S	70°47'W
Goldschmidt Cirque	80°44'S	22°48'W
Goldstream Peak	86°41'S	148°30'W
Gordon Nunataks	72°53'S	63°48'W
Gothic Mountains	86°00'S	150°00'W
Goward Peak	69°36'S	72°26'W
Grizzly Peak	85°58'S	151°25'W
Guyatt Ridge	80°38'S	29°27'W
Hadley Point	73°55'S	113°58'W
Hageman Peak	71°43'S	70°48'W
Hahn, Mount	69°17'S	70°14'W
Hamilton Ice Piedmont	74°31'S	110°18'W
Hammer Point	62°21'S	59°39'W
Harmon Bay	74°15'S	110°52'W
Haskard Highlands	80°30'S	29°15'W
Hatch Plain	80°44'S	25°43'W
Hayden Peak	74°41'S	111°41'W
Heezen Glacier	72°40'S	61°10'W
Helm Peak	69°29'S	67°50'W
Hess Mountains	72°00'S	62°30'W
Hjort Massif	72°08'S	61°24'W
Hodge Escarpment	83°03'S	50°11'W
Holden Nunataks	72°42'S	65°00'W
Hollingworth Cliffs	80°26'S	25°33'W
Holmes Hills	72°08'S	63°25'W
Holmes Summit	80°40'S	24°39'W
Holt, Mount	69°25'S	71°43'W
Hook, Mount	83°20'S	50°00'W
Horse Bluff	71°18'S	67°34'W
Horton Glacier	67°33'S	68°30'W
Hourglass Buttress	86°40'S	146°28'W
Houser Peak*	68°22'S	65°33'W
Huie Cliffs	83°19'S	51°03'W
Hummer, Mount	83°17'S	50°06'W
Hummer, Point	74°22'S	110°15'W
Hurley Glacier	67°34'S	68°32'W
Inca Point	62°18'S	59°12'W
Ivory Tower	85°28'S	142°24'W
Jackson Tooth	80°25'S	23°16'W
Jaeger Table	82°36'S	52°30'W
Jamieson Ridge	80°27'S	25°53'W
Jasper Point	62°11'S	58°55'W
Jeffries Bluff	73°48'S	60°14'W
Jenkins Heights	74°48'S	114°20'W
Kelsey, Mount	80°27'S	22°19'W
Kendall Basin	80°15'S	25°39'W
Keys Glacier	74°48'S	114°00'W

Khamsin Pass	69°29'S	67°45'W
Kite Stream	77°23'S	162°07' E
Klinck Nunatak	72°04'S	63°59'W
Klinger Ridge	74°43'S	114°00'W
Kovacs Glacier	83°11'S	49°15'W
Krieger Peak	71°46'S	70°35'W
Kuno Cirque	80°41'S	24°55'W
Landers Peak	69°26'S	71°16'W
Landrum Island	69°14'S	68°20'W
Lapworth Cirque	80°44'S	23°08'W
Lasher Spur	69°06'S	66°42'W
Lindqvist Nunatak	80°39'S	20°38'W
Linnaeus Terrace	77°36'S	161°05' E
Lord Bank	67°50'S	69°15'W
Lord Nunatak	80°21'S	24°01'W
Lundström Knoll	80°31'S	20°25'W
MacKay Peak	62°43'S	60°18'W
Maclaren Monolith	80°20'S	25°23'W
MacQuarrie Edge	80°32'S	30°03'W
Magnetite Bluff	83°22'S	51°15'W
Mahalak Bluffs	68°17'S	65°23'W
Mandolin Hills	69°55'S	67°20'W
Mantell Screes	80°38'S	24°26'W
Marin Bluff	69°25'S	68°36'W
Mathys Bank	80°19'S	28°30'W
Matthews Peak	67°40'S	67°47'W
Maumee Ice Piedmont	74°44'S	113°22'W
Mayo Peak	74°49'S	110°36'W
McAllister, Mount	68°42'S	65°54'W
McClinton Glacier	74°40'S	114°00'W
McHugh Peak	69°51'S	68°06'W
M'Clintock Bastion	80°28'S	22°28'W
Meade Nunatak	80°23'S	21°58'W
Merrick Point	74°28'S	110°09'W
Messent Peak	69°24'S	66°13'W
Meteorite Hills	79°40'S	155°36' E
Meunier, Mount	74°58'S	113°19'W
Midge Lake	62°38'S	61°06'W
Miller Ice Rise	69°05'S	67°38'W
Mistral Ridge	69°33'S	68°04'W
Miyoda Cliff	68°22'S	65°05'W
Moider Glacier	67°43'S	67°38'W
Molina Point	64°48'S	62°51'W
Moore Dome	74°20'S	111°20'W
Moore Island	69°40'S	68°39'W
Moran Glacier	69°15'S	70°15'W
Morrill Peak	69°39'S	72°18'W
Moutonnée Valley	70°51'S	68°25'W
Mummery Cliff	80°27'S	21°23'W
Muñoz Point	64°50'S	62°54'W
Murchison Cirque	80°42'S	24°33'W
Negro Hill	62°39'S	61°00'W
Nemo Glacier	67°43'S	67°22'W
Nicol Crags	80°44'S	24°05'W
Niggli Nunataks	80°38'S	23°20'W
Noel, Mount	69°55'S	67°55'W
Norman Peak	69°09'S	66°08'W
Nutt Bluff	82°34'S	51°45'W
Obrecht Pyramid	68°09'S	65°32'W
Ocoa Point	62°37'S	61°08'W
Oliver Island	69°19'S	68°37'W
O'Neill Point	64°49'S	63°06'W
Organ Pipes, The	82°37'S	52°42'W
Oscar Cove	64°55'S	62°55'W
Otter Highlands	80°38'S	30°00'W
Overton Peak	69°41'S	72°05'W
Page Bluff	69°38'S	66°11'W
Pampero Pass	69°31'S	68°07'W
Paulus Glacier	69°24'S	70°31'W
Pawley Nunataks	69°59'S	67°36'W
Pawson Peak	62°11'S	58°28'W
Penca Hill	62°37'S	61°07'W
Petrie Ice Rises	70°33'S	72°12'W
Piñero Peak	67°34'S	67°49'W
Pioneers Escarpment	80°28'S	21°10'W
Platt Cliffs	62°11'S	58°35'W
Platt Point	68°36'S	64°14'W
Polarstar Ridge	71°49'S	70°27'W
Poldervaart Edge	80°45'S	26°00'W
Potter Peninsula	62°15'S	58°40'W
Preslik Spur	82°32'S	51°20'W
Pyroxenite Promontory	82°37'S	53°00'W
Ramirez Island	69°09'S	68°28'W
Ramsay Wedge	80°26'S	25°43'W
Rautio Nunatak	82°37'S	53°03'W
Ray Promontory	62°36'S	61°09'W
Reichle Mesa	68°09'S	65°03'W
Rendezvous Rocks	69°35'S	67°38'W
Reptile Ridge	67°33'S	68°11'W
Rhyolite Head	62°10'S	58°36'W
Richter Peaks	71°20'S	70°21'W
Ritala Spur	83°07'S	48°57'W
Rojas Peak	64°49'S	62°55'W
Rowe Bluff	68°01'S	65°33'W
Rudolphy Point	64°53'S	63°07'W
Runcorn Glacier	72°06'S	62°34'W
Rydelek Icefalls	74°28'S	113°50'W
Saddleback Ridge	62°35'S	59°56'W
Sagehen Nunataks	86°30'S	153°30'W
Sanctuary Glacier	86°01'S	150°50'W
San Eladio Point	64°50'S	63°07'W
Saunders Valley	62°12'S	58°59'W
Sauria Buttress	80°32'S	20°24'W
Sayer Nunatak	62°28'S	60°08'W
Schenck Peak	69°40'S	72°25'W
Schimper Glacier	80°18'S	20°05'W
Scott Uplands	72°40'S	66°00'W
Sealer Hill	62°40'S	61°06'W
Sentry Cove	62°13'S	58°26'W
Sepúlveda Point	64°31'S	61°35'W
Sevier Nunatak	71°22'S	70°15'W
Shaler Cliffs	80°17'S	25°29'W
Sheldon Glacier	67°30'S	68°23'W
Sheridan Bluff	86°53'S	153°30'W
Sheriff Cliffs	83°24'S	50°37'W
Shotton Snowfield	80°35'S	23°15'W
Siebert Rock	64°49'S	63°02'W
Simoom Hill	69°28'S	68°00'W
Singer Glacier	74°15'S	113°52'W
Sirocco Glacier	69°25'S	68°31'W
Smellie, Point	62°39'S	61°09'W
Smythe Shoulder	74°18'S	113°53'W
Snell, Mount	70°20'S	71°38'W
Sorrenson Glacier	74°28'S	111°22'W
Southard Promontory	66°56'S	64°48'W
Spath Crest	80°39'S	26°12'W
Spaulding Peninsula	74°26'S	116°00'W
Spectre, The	86°06'S	150°10'W
Spiess Glacier	72°15'S	61°15'W
Spillway Icefall	85°03'S	166°30'W
Spindrift Bluff	69°35'S	68°02'W
Spirogyra Lake	60°42'S	45°39'W
Stagnaro, Mount	77°10'S	144°20'W
Stansbury Peninsula	62°14'S	59°00'W
Start Hill	62°36'S	61°11'W
Statham Peak	67°41'S	67°47'W
Stokes Peaks	67°24'S	68°09'W

Stoltz Island	69°15'S	72°16'W
Stork Ridge	67°31'S	68°12'W
Strachey Stump	80°41'S	23°10'W
Striation Valley	70°53'S	68°23'W
Stride Peak	67°41'S	67°38'W
Stump, Mount	86°11'S	153°02'W
Sumgin Buttress	80°18'S	25°44'W
Sverdrup Nunataks	72°45'S	63°15'W
Sweeny Inlet	74°27'S	115°20'W
Swinnerton Ledge	80°43'S	22°28'W
Telefon Point	62°14'S	58°28'W
Tharp Ice Rise	72°25'S	59°54'W
Thompo Icefall	83°18'S	50°08'W
Thuma Peak	69°39'S	72°10'W
Tindley Peaks	71°18'S	67°26'W
Tioga Lake	60°42'S	45°39'W
Toadstool Rocks	68°50'S	69°25'W
Tofani Glacier	68°21'S	65°35'W
Tongue Peak	86°34'S	153°02'W
Tranquil Lake	60°42'S	45°39'W
Tranquillity Valley	82°36'S	52°55'W
True Glacier	74°38'S	111°45'W
True Hills	80°13'S	2[illegible]°51'W
Trueman Terraces	80°43'S	22°41'W
Tucker Point	73°57'S	114°49'W
Turner Glacier	67°37'S	68°29'W
Venetz Peak	80°23'S	25°30'W
Vere Ice Rise	70°27'S	72°44'W
Vigen Cliffs	83°23'S	50°07'W
Villard Point	62°37'S	61°04'W
Vivallos Glacier	64°52'S	62°49'W
Wade Ice Rise	69°01'S	67°07'W
Walter Glacier	69°17'S	70°26'W
Warden Pass	80°28'S	28°08'W
Warren Ice Piedmont	70°00'S	68°15'W
Watts Needle	80°44'S	24°59'W
Watts Summit	83°12'S	50°31'W
Weaver Peninsula	62°12'S	58°48'W
Webb Peak	69°38'S	66°28'W
Webster Pass	74°34'S	111°09'W
Wegener, Mount	80°44'S	23°31'W
Wegener Range	72°42'S	62°23'W
Welcome Pass	82°35'S	52°45'W
West Bay	69°21'S	68°26'W
Wheat, Mount	64°50'S	63°23'W
Whitney Island	69°40'S	68°31'W
Whittle Peninsula	63°49'S	59°48'W
Whymper Spur	80°25'S	21°29'W
Wiggans Hills	80°11'S	27°03'W
Wilson Mountains	72°15'S	61°50'W
Worcester Summit	82°36'S	52°22'W
Wormald Ice Piedmont	67°29'S	68°05'W
Wright Pass	74°45'S	110°35'W
Wright Spires	69°30'S	68°30'W
Wubbold Glacier	69°20'S	71°41'W
Wujek Ridge	82°28'S	50°55'W
Wyatt Hill	74°32'S	110°27'W
Wyeth Heights	80°45'S	29°33'W
Yates Spur	68°41'S	64°57'W
Zephyr Glacier	69°28'S	68°30'W
Zittel Cliffs	80°40'S	25°59'W
Zonda Glacier	69°33'S	68°30'W
Zonda Towers	69°34'S	68°18'W
Zuniga Glacier	74°34'S	111°52'W



NSF photo by Russ Kinne.

A snow storm engulfs a camp in University Valley (southern Victoria Land).

Emergency medical evacuation from McMurdo Station

U. S. Navy photo (XAM-0016-C-10-80) by Brad F. Guttilla

An Air Force C-141 airplane lands on the ice runway near McMurdo Station in early October 1980. In late September 1982 a similar airplane made an emergency flight to McMurdo Station to evacuate T. W. Busler to Christchurch Hospital.

Because of an accident that required immediate evacuation of a member of the Naval Support Force Antarctica (NSFA), C-141 flights to McMurdo Station for the 1981-1982 summer began 6 days early on 28 September 1982. While carrying a section of pipe on 27 September, Terry W. Busler slipped and struck the back of his head and lower back. After examining Busler, the Navy doctor in residence recommended that he be evacuated immediately to Christchurch, New Zealand. Subsequent consultation by telephone with a New Zealand neurosurgeon confirmed this decision, and plans for the evacuation were set in motion.

Although early season flights to McMurdo Station by LC-130 had been made in late August, regular season flights were not scheduled to begin until 4 October. Preparation of the ice runway, along with placement of the necessary navigational aids, had been completed for these October flights, but the equipment had not yet been calibrated. Also all of the antarctic program's LC-130 airplanes were in the United States.

Because Busler was in guarded condition, other arrangements were necessary to move him to a hospital for treatment. Hickam Air Force Base in Honolulu and the Air Force's 9th Aeromedical Evacuation Squadron arranged for an Air Force C-141 in transit near Australia to be diverted for the mission. The Royal New Zealand Air Force and the Antarctic Division of New Zealand's Department of Scientific and Industrial Research offered to assist.

The C-141 arrived at the Christchurch, New Zealand, airport at 2 a.m. on 28 September, and preparations for the trip south began. Because of his antarctic flying experience, an Air Force captain assigned to a Christchurch detachment was chosen to be a part of the nine-man crew; a Navy hospital corpsman trained in medical evacuation procedures also joined the crew at Christchurch. After only 12 hours to prepare for the flight, the airplane left for Antarctica at 2:45 p.m. on 28 September.

Arriving in the early evening at McMurdo Station, the C-141 crew found that the sea ice runway and navigational systems were in excellent condition. By 2:30 a.m. on 29 September the C-141 had returned to Christchurch with Busler. At the airport an ambulance was waiting to take Mr. Busler to Christchurch Hospital, where he was placed under the care of a neurosurgeon. Although the patient's condition remained serious, his chances for recovery were considered good.

Antarctic Geoscience

In May 1982 the University of Wisconsin published *Antarctic Geoscience*, edited by Campbell Craddock, which contains the 151 papers resulting from the Third Symposium on Antarctic Geology and Geophysics, held at Madison, Wisconsin, 22-27 August 1977. The 1,216-page tome is divided into 12 sections: Gondwanaland (11 papers), Scotia Arc region (39), East Antarctica shield (14), Upper Precambrian-Paleozoic rocks (11), paleontology (8), igneous rocks (14), structural geology and tectonics (9), mineral deposits (4), crustal structure (13), subglacial morphology (4), marine geology (8), and Cenozoic history (16).

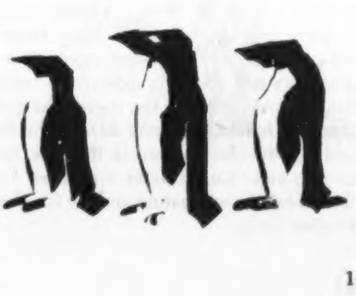
The hardbound volume is illustrated with photographs and drawings. A pocket contains a folded 1:5,000,000-scale geologic map of the continent.

The National Science Foundation provided partial support for both the conference and the proceedings volume, which is available for $35 from the University of Wisconsin Press, 114 N. Murray Street, Madison, Wisconsin 53715 (telephone 608/162-8782).

The two earlier antarctic earth science conferences, held in 1963 and 1979, resulted in these books:

Adie, Raymond J., ed. 1972. *Antarctic Geology and Geophysics*. Oslo: Universitetsforlaget. 886 pages.

Adie, Raymond J., ed. 1964. *Antarctic Geology*. New York: John Wiley & Sons, Inc. 778 pages.



Antarctic undersea feature names updated

The new edition of the *Gazetteer of Undersea Features*, published by the Defense Mapping Agency in 1982, includes 38 approved and 52 variant names for undersea features within the area south of 60°S. The gazetteer contains 6,000 names, 3,600 of which are approved by the Board on Geographic Names and the Secretary of the Interior, for features around the world and provides standard geographic feature names used by the Federal government. This edition supersedes previous gazetteers by the Board on Geographic Names and other Defense Mapping Agency publications and incorporates new names, changes to some older names, and other modifications approved since the 1971 edition.

The Board defines "undersea features" as those parts of the ocean floor or seabed that have measurable relief or that can be defined by relief. Geological or geophysical features (such as magnetic features) that have no surface expression do not receive approved names. For international standards, the Board follows as closely as possible the practices under consideration by the United Nations and the International Hydrographic Organization at the time of publication.

The gazetteer is divided into two sections, an alphabetized, cross-referenced list of approved and unapproved names and a list of the same names within blocks bounded by parallels and meridians at 30° intervals. At the beginning of the second section, a map illustrates these geographic divisions. The publication also contains a description of the Board's procedures for naming features, a glossary of accepted geographic terms, and forms and instructions for proposing names.

The list of 90 approved and unapproved names for undersea features south of 60°S follows this article.

In the first column of the list approved and unapproved names are given. If the name is unapproved, it is cross-referenced to the approved form by the word "see." The second column identifies the topographic feature to which the name applies. Usually this identification is the same as the generic term, but when a generic term that does not properly describe a feature has been retained in the name, the topographic identification will differ. The third and fourth columns contain the geographic coordinates. Coordinates are taken from the center of each feature and are for identification only.

The *Gazetteer of Undersea Features* (Stock no. GAZGNUNDERSEA) may be obtained by written request from: DMAODS, Attention: DDCP, 6500 Brookes Lane, Washington, D.C. 20315.

Adelie Depression: see Mertz-Ninnis Valley	valley	67°25'S	146°00'E
Adelie Trough: see Adelie Valley	valley	65°30'S	136°00'E
Adelie Valley	valley	65°30'S	136°00'E
Afrikansko-Antarkticheskaya Kotlovina: see Atlantic-Indian Basin	basin	60°00'S	15°00'E
Amundsen Basin: see Southeast Pacific Basin	basin	60°00'S	115°00'W
Antarctic Pacific Ridge: see Pacific-Antarctic Ridge	ridge	62°00S'	157°00'W
Atlantic Antarctic Basin: see Atlantic-Indian Basin	basin	60°00'S	15°00'E
Atlantic-Indian Antarctic Basin: see Atlantic-Indian Basin	basin	60°00'S	15°00'E
Atlantic-Indian Basin	basin	60°00'S	15°00'E
Australian Antarctic Basin: see South Indian Basin	basin	60°00'S	120°00'E
Avstralo-Antarkticheskaya Kotlovina: see South Indian Basin	basin	60°00'S	120°00'E
Balleny Basin	basin	67°00'S	170°00'E
Balleny Fracture Zone	fracture zone	62°00'S	156°00'E
Balleny Trough	trough	66°00'S	158°00'E
Bellinghausen Abyssal Plain: see Bellingshausen Plain	plain	60°00'S	90°00'W
Bellinghausen Basin: see Southeast Pacific Basin	basin	60°00'S	115°00'W
Bellinghausen-Mulde: see Southeast Pacific Basin	basin	60°00'S	115°00'W
Bellingshausen Plain	plain	64°00'S	90°00'W
Bellinsgauzena, Kotlovina: see Southeast Pacific Basin	basin	60°00'S	115°00'W
Berkner Bank	bank	75°00'S	48°00'W
Bower Canyon: see Bowers Canyon	canyon	71°55'S	172°30'E
Bowers Canyon	canyon	71°55'S	172°30'E
Bransfield Trough	trough	61°30'S	54°00'W
Brategg Bank	bank	65°16'S	68°35'W
Bratteggen: see Brategg Bank	bank	65°16'S	68°35'W
Bruce Ridge	ridge	60°00'S	35°00'W
Bruce Rise: see Bruce Spur	spur	63°30'S	101°15'E
Bruce Spur	spur	63°30'S	101°15'E
Brus, Banka: see Bruce Spur	spur	63°30'S	101°15'E
Dibble Basin	basin	65°20'S	133°00'E
Dibble Depression: see Dibble Basin	basin	65°20'S	133°00'E
Drygalski Basin	basin	74°50'S	166°30'E
Drygalsky Basin: see Drygalski Basin	basin	74°50'S	166°30'E
Dumont D'Urville Trough: see Adelie Valley	valley	65°30'S	136°00'E
Eastern-Indian Antarctic Basin: see South Indian Basin	basin	60°00'S	120°00'E
For Ledis, Banka: see Four Ladies Bank	bank	67°30'S	77°30'E
Four Ladies Bank	bank	67°30'S	77°30'E
Fram Bank	bank	67°18'S	70°00'E
Gunnerus Bank	bank	68°00'S	33°00'E
Hjort Fracture Zone	fracture zone	62°00'S	163°00'E
Indian-Antarctic Basin: see South Indian Basin	basin	60°00'S	120°00'E
Iselin Bank: see Iselin Seamount	seamount	70°45'S	178°15'W
Iselin Bank	spur	72°30'S	179°00'W
Iselin Seamount	seamount	70°45'S	178°15'W

Knox Basin: see South Indian Basin	basin	60°00'S	120°00'E
Maud Bank: see Maud Seamount	seamount	65°00'S	2°35'E
Maudbanken: see Maud Seamount	seamount	65°00'S	2°35'E
Maud Seamount	seamount	65°00'S	2°35'E
Mertz-Ninnis Trough: see Mertz-Ninnis Valley	valley	67°25'S	146°00'E
Mertz-Ninnis Valley	valley	67°25'S	146°00'E
Mod, Banka: see Maud Seamount	seamount	65°00'S	2°35'E
Mod, Gora: see Maud Seamount	seamount	65°00'S	2°35'E
Mod, Vozvyshennost: see Maud Seamount	seamount	65°00'S	2°35'E
Nordenskjöld Basin	basin	76°03'S	165°00'E
Pacific-Antarctic Basin: see Southeast Pacific Basin	basin	60°00'S	115°00'W
Pacific-Antarctic Ridge	ridge	62°00'S	157°00'W
Pacific South Polar Basin: see Southeast Pacific Basin	basin	60°00'S	115°00'W
Pacifique Sud, Dorsale du: see Pacific-Antarctic Ridge	ridge	62°00'S	157°00'W
Pazifisch-Antarktisches Becken: see Southeast Pacific Basin	basin	60°00'S	115°00'W
Pazifisches Sudpolar Becken: see Southeast Pacific Basin	basin	60°00'S	115°00'W
Pennel, Banka: see Pennell Bank	bank	74°30'S	179°59'E
Pennell Bank	bank	74°30'S	179°59'E
Petersen Bank	bank	65°45'S	109°55'E
Porpoise Basin	basin	66°10'S	128°30'E
Porpoise Trough: see Porpoise Basin	basin	66°10'S	128°30'E
Powell Basin	basin	62°15'S	49°30'W
Scott Island Bank	ridge	67°45'S	179°55'W
Southeast Pacific Basin	basin	60°00'S	115°00'W
South Indian Basin	basin	60°00'S	120°00'E
South Indian Ocean Basin: see South Indian Basin	basin	60°00'S	120°00'E
South Orkney Ridge	ridge	60°00'S	40°00'W
South Orkney Trough	trough	60°00'S	45°00'W
South Pacific Ridge: see Pacific-Antarctic Ridge	ridge	62°00'S	157°00'W
South Pacific Rise: see Pacific-Antarctic Ridge	ridge	62°00'S	157°00'W
South Shetland Trough	trough	61°00'S	59°30'W
Südpazifischer Rucken: see Pacific-Antarctic Ridge	ridge	62°00'S	157°00'W
Tressler Bank	bank	65°00'S	95°00'E
Umitaka Bank	seamount	67°25'S	167°00'E
Valdivia Basin: see Atlantic-Indian Basin	basin	60°00'S	15°00'E
Vanderford Strath: see Vanderford Valley	valley	66°25'S	110°10'E
Vanderford Submarine Valley: see Vanderford Valley	valley	66°25'S	110°10'E
Vanderford Valley	valley	66°25'S	110°10'E
Vaughan Bank	seamount	67°37'S	163°30'E
Western Indian Antarctic Basin see Atlantic-Indian Basin	basin	60°00'S	15°00'E
Westliches Indisches Sudpolar Becken: see Atlantic-Indian Basin	basin	60°00'S	15°00'E
Whales Bay Deeps: see Whales Bay Furrows	furrows	78°00'S	169°00'W
Whales Bay Furrows	furrows	78°00'S	169°00'W
Yuzhnogo Mysa, Zholob: see Storfjordrenna	valley	76°00'S	17°00'E
Yuzhno-Tikhookeanskiy Khrebet: see Pacific-Antarctic Ridge	ridge	62°00'S	157°00'W
Yuzhno-Tikhookeanskoye Podnyatiye: see Pacific-Antarctic Ridge	ridge	62°00'S	157°00'W

Soviet literature submitted for translation

The National Science Foundation has submitted the following titles to Amerind Publishing Company, New Delhi, for translation into English and publication. Readers wishing to nominate additional books for translation into English should contact the Polar Information Program, Division of Polar Programs, National Science Foundation, Washington, D.C. 20550. (202/357-7817).

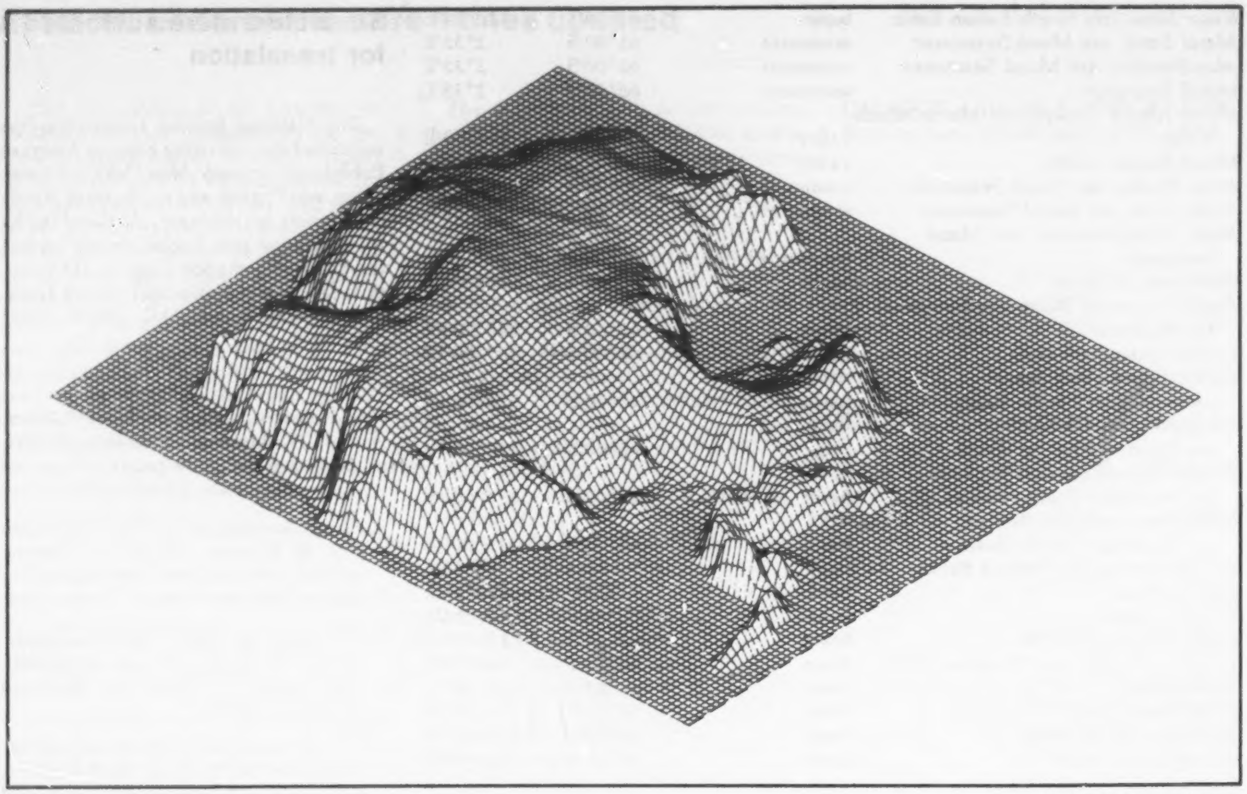
The Antarctic. The Committee Reports, No. 19. Moscow: Publishing Office, Nauka. 1980. 209 pages. (Expected December 1983). TT 81-52174.

Data of Glaciological Studies. Publication No. 40. Moscow: Academy of Sciences of the U.S.S.R. 1980. 288 pages. (Expected December 1983). TT 81-52175.

I. M. Dolgin, ed. 1980. *Antarctic Climatic Research.* Leningrad, Gidrometeoizdat. 206 pages. TT 82-52190. (Expected December 1983).

T. G. Lubimova, ed. 1980. *Biological Resources of the Antarctic Krill.* Moscow. 251 pages. TT 82-01000. (Expected March 1984).

Arctic Ice and its Contemporary Natural Environment. Leningrad, Gidrometeoizdat. 1981. 136 pages. TT 82-01001. (Being translated by University of Washington.)



Scott Polar Research Institute

This three-dimensional isometric view of the surface of the antarctic ice sheet is an example of computer-aided graphics used in the new glaciological and geophysical folio.

Glaciological and geophysical folio published by Scott Polar Institute

The results of an intensive 10-year international program of airborne geophysics in Antarctica have been synthesized and published, along with additional physical information, as *Antarctica: Glaciological and geophysical folio* by the Scott Polar Research Institute. David J. Drewry is editor. The folio, an up-to-date compilation of measured physical information, comprises a set of large-format color maps, each with illustrations, graphs, tabulated data, and 2,000 words of text. According to a brochure, it presents a considerable body of new data including:

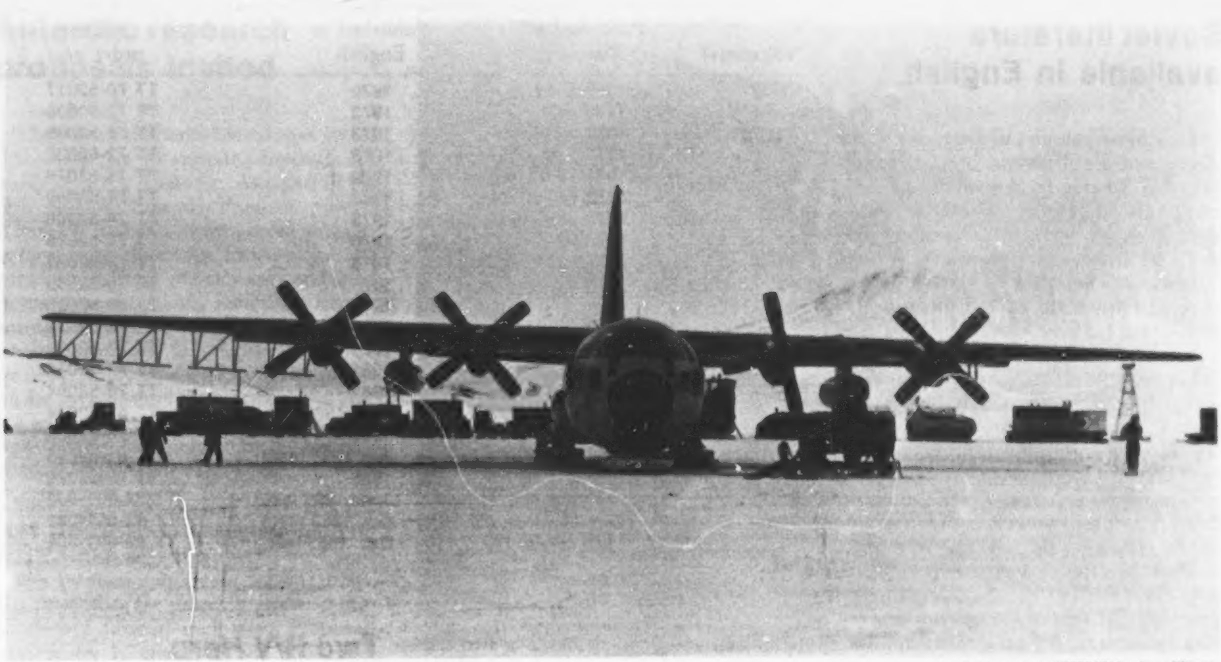
- newly compiled coastline of Antarctica
- fully integrated sub-glacial bedrock and ocean bathymetric contour map
- new calculations of area of Antarctica, mean ice thickness and ice volume
- internal structure of the antarctic ice sheet
- complete contour map of Antarctica after removal of ice load and isostatic recovery
- over 300 determinations of depth to magnetic basement in West Antarctica
- delimination of principal crustal plates from geophysical studies.

The folio comprises the following 13 map sheets:

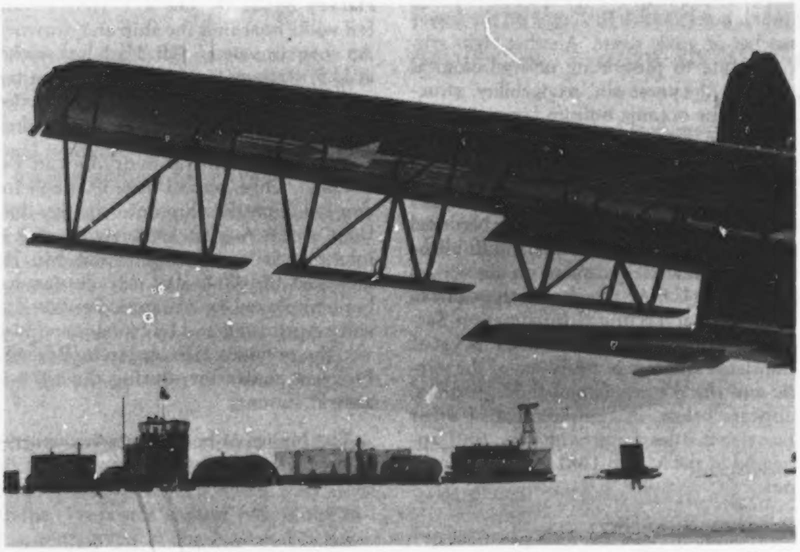
1. Introduction to radio echo sounding.
2. The surface of the antarctic ice sheet.
3. The bedrock surface of Antarctica.
4. Ice sheet thickness and volume.
5. Driving stresses in the antarctic ice sheet.
6. Isostatically adjusted bedrock surface of Antarctica.
7. Residual magnetic field in West Antarctica.
8. Magnetic basement in West Antarctica.
9. Internal layering of the antarctic ice sheet.
10. Antarctic surface temperature and accumulation.
11. Radar characteristics of the Ross Ice Shelf.
12. Ice sheet drainage basins, balance and measured ice velocities and sub-glacial water.
13. Geological units of Antarctica.

Scott Polar Research Institute (University of Cambridge) collected much of the data for the folio in collaboration with the Technical University of Denmark, the U.S. Geological Survey, and the Johns Hopkins University. Support was provided by the U.K. Natural Environment Research Council and the U.S. National Science Foundation. Publication was supported by British Petroleum and Phillips Petroleum.

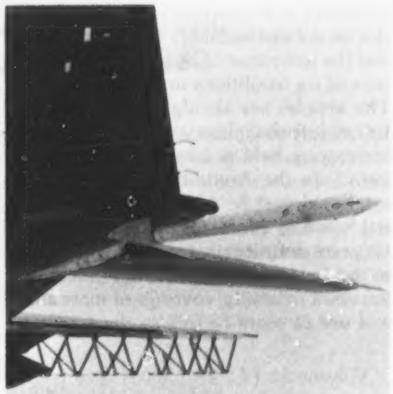
The folio, which costs 59 pounds (U.K.), can be purchased from Folio Orders, Scott Polar Research Institute, Lensfield Road, Cambridge CB2, 1ER, England. Sheets 2 through 9 in their binder were to be ready in February 1983; the remaining sheets will be forwarded free of charge in mid-1983. Orders from individuals must be prepaid (publisher pays postage).



U. S. Navy photo (780349) by Jerry Moore.



U. S. Navy photo (780347) by Jerry Moore.



U. S. Navy photo (780345) by Jerry Moore.

LC-130R supports research

In 1976 LC-130R 159131 (top), a ski-equipped Hercules airplane, was modified for scientific research. Initially sensor probes and apertures and a pallet-mounted data logging system called the airborne research data system (ARDS) were installed. During the 1976-77 austral summer the equipment was tested and, along with additional sensors, used in meteorological investigations. In early January 1978 radio-echo ice sounding equipment and a magnetometer system were added. Between 1978 and 1980 U. S. and British investigators used this airplane to gather data that have been synthesized for the Antarctica: Glaciological and Geophysical Folio. The National Science Foundation provided support for the project, which includes a systematic grid network of airborne geophysical soundings for 50 percent of the continent, from 1967 to 1980. On the right the antennas that send out radar signals from the airplane to the ice can be seen attached to the wing. The signals bounce off the ice surface, internal layers, and the bedrock below; the return times are proportional to ice thickness. On the left the magnetometer, used to measure the earth's magnetic field, protrudes from the airplane's tail section.

Soviet literature available in English

Four more volumes of *Problems of the Arctic and the Antarctic*, originally published in Russian by the Arctic and Antarctic Scientific Research Institute, Leningrad, have just been translated into English and published. Each volume contains papers describing progress in research with which the writers are involved. Some review papers are included.

Volume 39 (TT 75-52078), 188 pages, was published in Russian in 1972. Its 21 papers discuss basic problems tackled by the Institute during the ninth 5-year plan (1971-1975): hydrological variability; oceanic flow, icebergs, and ice cover in the Arctic Basin (seven papers); atmospheric conditions and weather (six papers); excavations at the ancient town Mangazeya; magnetic perturbations during the International Year of the Quiet Sun, very long radio waves; ice navigation; and Norwegian studies in Spitsbergen. While most of these papers deal with the Arctic, there is a wholly antarctic paper on variability of the mean monthly temperatures in the surface layer as recorded at eight stations between 1957 and 1967.

Volume 50 (TT 78-52004), 166 pages, published in Russian in 1977, has 27 articles on the methodology of ice forecasting and the technique of estimating the influence of ice conditions on fleet operations. The articles are abridged from the All-Union Interdisciplinary Conference on ice forecasting held at Leningrad in January 1974. "In the Arctic the navigation season has almost doubled," notes the Editorial Board in a foreword. "During the last 10 years definite progress has been made in the field of ice forecasting," including increased reliability, coverage of more areas, and use of more factors in the forecasts.

Volume 52 (TT 78-52005), 128 pages, was published in Russian in 1977. Some of its papers were written by scientists of the Murmansk branch of the Arctic and Antarctic Institute. A review paper by F. S. Terziev identifies the port of Murmansk as the gateway to the Arctic. Many polar oceanic expeditions originate there, and the Institute's Murmansk branch, set up in 1972, is called the first hydrometeorological research institute north of the Arctic Circle. The papers deal with the hydrometeorological regime, including methods of diagnosis and prognosis, and pollution in the Barents, Norwegian, and Greenland seas, the North Atlantic, and off the Kola Peninsula. Four articles are devoted to the thermal state of the Barents Sea, and several discuss the space-time variability of ice cover in the North Atlantic. Arctic synoptic meteorology is discussed in two articles. None of the 16 papers deals with the Antarctic.

Volume 54 (TT 79-52026), 122 pages, was published in Russian in 1978. It is devoted to hydrology and meteorology. Four papers review investigations at the Leningrad institute, results of the Polar Experiment, large-scale ocean-atmosphere interactions, and hydrology of the lower reaches of arctic rivers. Another eight articles relate to processing of hydrological data, ice thickness and navigability, structure of the oceanic bottom layer, and climatology. There is an article on computer analysis of medico-geographical data from the 12th Soviet Antarctic Expedition.

The books, translated for the National Science Foundation by Amerind Publishing Co., New Delhi, using excess rupees held by the U.S.A., may be purchased from the National Technical Information Service, Springfield, Virginia 22161. A list of translated volumes of *Problems of the Arctic and the Antarctic*, and those in press, appears below. A complete list of other translated titles (approximately 100) appeared in the March 1981 *Antarctic Journal*.

Volume(s)	Published in Russian	Published in English	NTIS order no.
29-32	1968-1969	1970	TT 70-50017
33-35	1970	1973	TT 72-50006
36-37	1970	1973	TT 72-52006
38	1971	1973	TT 72-52007
39	1972	1982	TT 75-52078
40	1972	1973	TT 72-50089
41	1973	1975	TT 74-52009
42	1973	1976	TT 75-52018
43-44	1974	1978	TT 75-52082
45	1974	1979	TT 75-52083
46	1975	1979	TT 76-52023
47	1976	1977	TT 76-52038
48	1976	1981	TT 77-52011
49	1977	1981	TT 77-52041
50	1977	1982	TT 78-52004
51	1981	June 1983 (est.)	TT 81-52034
52	1977	1982	TT 78-52005
53	1981	July 1983 (est.)	TT 81-52035
54	1978	1982	TT 79-52026
55	1981	June 1983 (est.)	TT 82-001-003
56	1981	Oct. 1983 (est.)	TT 82-001-002
57	1981	Dec. 1983 (est.)	TT 82-001-004

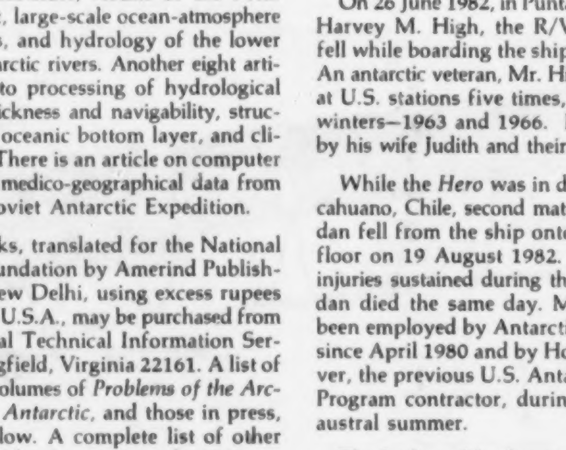
Two R/V *Hero* crewmen die

The National Science Foundation regrets to announce the deaths of two members of the Nation's antarctic program.

On 26 June 1982, in Punta Arenas, Chile, Harvey M. High, the R/V *Hero*'s cook, fell while boarding the ship and drowned. An antarctic veteran, Mr. High had worked at U.S. stations five times, including two winters—1963 and 1966. He is survived by his wife Judith and their three children.

While the *Hero* was in drydock in Talcahuano, Chile, second mate O. Keith Jordan fell from the ship onto the dry-dock floor on 19 August 1982. As a result of injuries sustained during the fall, Mr. Jordan died the same day. Mr. Jordan had been employed by Antarctic Services Inc. since April 1980 and by Holmes and Narver, the previous U.S. Antarctic Research Program contractor, during the 1979-80 austral summer.

The bodies of both men were returned to the United States for memorial services.



Antarctic research proposals invited

The National Science Foundation invites U.S. scientists to submit proposals for research in the Antarctic. As a part of the U.S. Antarctic Research Program, projects in biology, medical sciences, ocean sciences, earth sciences, glaciology, meteorology, and upper atmosphere physics are conducted at year-round stations, temporary camps during the austral summer, and aboard research ships and U.S. Coast Guard icebreakers. Approximately 85 projects carried out by investigators from universities and, to a lesser extent, federal agencies and other organizations are supported by the National Science Foundation each year.

The process of selecting projects is initiated when scientists develop research proposals, which are submitted to the Foundation by their employing organizations. The target date for properly prepared proposals is 1 June of each year. Proposals received by 1 June 1983 will be considered for:

- research in Antarctica during the 1984-1985 austral summer season (September 1984 through March 1985) and extending through the southern hemisphere winter of 1985;
- research or data analysis in the United States to commence in early 1984.

Projects requiring large amounts of equipment in Antarctica may not be fielded until 1 year later than above so that equipment may be transported by ship. Grant award notifications for 1983 proposals will be made beginning early 1984.

Investigators who require only operational support and no direct funding must still submit a formal proposal so that their requirements can be evaluated in competition with the requirements of other investigators. Research may be conducted by individual investigators, small teams, or large interdisciplinary groups.

Interested scientists should investigate requirements for eligibility before submitting proposals in conjuction with their institutions. Proposals should follow the instructions given in the National Science Foundation booklet *Grants for Scientific and Engineering Research* (NSF 81-79) and should contain project descriptions no longer than 15 single-spaced pages. *Proposal preparation kits* must be used; they include the NSF booklet, descriptions of antarctic research opportunities and activities, and all necessary forms and instructions. To get a kit, contact the Polar Information Program, Division of Polar Programs, National Science Foundation, Washington, D.C. 20550 (202/357-7817).

U. S. Navy photo (XAM-0052-11-79) by Brian R. Worth

Near Lake Vanda in Wright Valley, southern Victoria Land, George Denton (University of Maine at Orono), Jim Leide, and Bjorn Anderson gather around Jim Bockheim, whose hat shows just above the edge of a pit in which he is standing. Dr. Bockheim is pointing out to the group aspects of soil formation that will aid in their investigation of changes in Lake Vanda's shoreline in the past.

Foundation awards of funds for antarctic projects, 1 July to 30 September 1982

Following is a list of National Science Foundation antarctic awards made from 1 July to 30 September 1982. Each item contains the name of the principal investigator or project manager, his or her institution, a shortened title of the project, the award number, and the amount awarded. If an investigator received a joint award from more than one Foundation program, the antarctic program funds are listed first, and the total amount of the award is listed in parentheses. Awards numbers, for awards initiated by the Division of Polar Programs, contain the prefix DPP and those initiated by the Division of Atmospheric Sciences prefix ATM.

Glaciology

Hughes, Terence J. University of Maine, Orono, Maine. Modelling the stability of the west antarctic ice sheet. DPP 81-07668. $69,324.

Kuivinen, Karl C. University of Nebraska, Lincoln, Nebraska. Coordination of ice core drilling. DPP 74-08414. $343,332.

Langway, Chester C. State University of New York, Buffalo, New York. Greenland Ice Sheet Program (GISP) ice core studies. DPP 81-17750. $11,272.

Oeschger, Hans. University of Bern, Bern, Switzerland. Analysis of gas and radioactive isotopes in ice cores from the South Pole. DPP 82-10926. $74,200.

Atmospheric sciences

Bering, Edgar A. University of Houston, Houston, Texas. Ionospheric electric fields over Siple Station, during the 1981-82 rocket-balloon campaign. DPP 82-07049. $63,000.

Holzworth, Robert H. University of Washington, Seattle, Washington. Electrodynamics of the middle atmosphere: superpressure balloon program. ATM 82-12283. $10,000. ($119,000).

Biology and medicine

Ainley, David G. Point Reyes Bird Observatory, Stinson Beach, California. Population biology of south polar skuas. DPP 79-20796. $24,809.

DeVries, Arthur L. University of Illinois, Urbana, Illinois. The role of glycopeptide antifreezes in freezing avoidance of fishes. DPP 81-16917. $98,233.

Dick, Elliot C. University of Wisconsin, Madison, Wisconsin. A study of respiratory virus transmission among the personnel at McMurdo Station during the winter-fly-in isolation period. DPP 80-15486. $88,875.

Erickson, Albert W. University of Washington, Seattle, Washington. Censuses of seals in the eastern sector of antarctic pack ice. DPP 82-10588. $68,444.

Friedmann, E. Imre. Florida State University, Tallahassee, Florida. Ecology of endolithic microorganisms in the ice-free regions, southern Victoria Land. DPP 80-17581. $51,959.

George, Robert Y. University of North Carolina, Wilmington, North Carolina. Growth and metabolism of marine crustaceans in relation to temperature and pressure. DPP 80-26535. $73,350.

Green, William J. Miami University, Oxford, Ohio. Trace metal and nutrient dynamics in lakes of the ice-free region of southern Victoria Land. DPP 81-17644. $60,754.

Holm-Hansen, Osmund. University of California, La Jolla, California. Phytoplankton standing crop and productivity in the East Wind Drift. DPP 82-12362. $26,049.

Hopkins, Thomas L. University of South Florida, Tampa, Florida. Trophodynamics of the mesopelagic fauna in southern ocean ecosystems. DPP 81-07510. $45,635.

Hunt, George L. University of California, Irvine, California. Marine bird distribution in relation to krill in the East Wind Drift. DPP 82-06052. $24,615.

Hushen, W. Timothy. National Academy of Sciences, Washington, D.C. United States participation in the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) program. DPP 82-12423. $26,275.

Jehl, Joseph R. Hubbs-Sea World Research Institution, San Diego, California. Circumpolar analysis of the marine mammals in pack ice. DPP 82-05761. $43,159.

Komarkova, Vera. University of Colorado, Boulder, Colorado. Plant communities of the Antarctic Peninsula near Palmer Station. DPP 82-01047. $41,352.

Muchmore, Harold G. Oklahoma Medical Research Foundation, Oklahoma City, Oklahoma. Virus shedding and immunity during isolation. DPP 80-20092. $131,844.

Risebrough, Robert W. University of California, Bodega Bay, California. Fluxes of synthetic, organic, biogenic, and petroleum-derived compounds through marine food webs which support and depend upon krill. DPP 77-22169. $44,637.

This 1978 photograph shows how snow has drifted over Amundsen-Scott South Pole Station since the major part of the station was completed in 1974. In the photograph's center, the meteorological building stands on stilts above the surface.

U.S. Navy photo (XAM-90135-11-78) by Dana B. Rabin.

U. S. Navy photo (XAM-128-12-79) by Swanstrom.

David Wilson from Northern Illinois University prepares to set off an explosive charge beneath the ice in McMurdo Sound. Seismic waves created by the explosion describe the rock composition and geologic structure of the seafloor. These data will contribute to a study of the tectonic history of the Ross Embayment and Transantarctic Mountains.

Robison, Bruce H. University of California, Santa Barbara, California. Trophodynamics of the mesopelagic fauna in southern ocean ecosystems. DPP 81-19621. $42,306.

Ross, Robin M. University of California, Santa Barbara, California. Krill egg production and larval survivorship. DPP 80-20739. $91,007.

Sullivan, Cornelius W. University of Southern California, Los Angeles, California. Factors influencing the growth and development of sea-ice microbial communities. DPP 81-17237. $99,120.

Trivelpiece, Wayne Z. Point Reyes Bird Observatory, Stinson Beach, California. Comparative behavioral and ecological studies of pygoscelid penguins in Admiralty Bay. DPP 81-17205. $66,065.

Van Vleet, Edward S. University of South Florida, St. Petersburg, Florida. Lipid biochemistry of midwater organisms. DPP 80-23961. $40,295.

Earth sciences

Bentley, Charles R. University of Wisconsin, Madison, Wisconsin. Comparative analysis of aeromagnetic and MAGSAT data. DPP 82-09484. $28,517.

Denton, George H. University of Maine, Orono, Maine. Cenozoic glacial history of the ice sheet. DPP 80-23714. $95,001.

Elston, Donald P. U.S. Geological Survey, Reston, Virginia. Magnetostratigraphy and sedimentology of the ice-free valleys (southern Victoria Land) and McMurdo Sound. DPP 81-20877. $17,000.

Kienle, Juergen. University of Alaska, Fairbanks, Alaska. Seismotectonics and volcanology of Mt. Erebus and vicinity. DPP 81-17968. $20,996.

Malin, Michael C. Arizona State University, Tempe, Arizona. Contemporary geomorphic processes in ice-free valleys, southern Victoria Land. DPP 82-06391. $19,318.

McGinnis, L. D. Northern Illinois University, DeKalb, Illinois. Seismic and gravity studies of the upper crust along the central Transantarctic Mountains. DPP 80-19995. $70,000.

Stephens, George C. George Washington University, Washington, D.C. Intergovernmental Personnel Act assignment to the Division of Polar Programs. DPP 82-18646. $20,932 ($32,900).

Meteorology

Hogan, Austin W. State University of New York, Albany, New York. Aerosol transport processes. DPP 81-15231. $93,947.

Murcray, David G. University of Denver, Denver, Colorado. Measurement of the column densities of water, nitric acid (HNO_3), fluorocarbons (CF_2Cl_2 and $CFCl_3$), and ozone (O_3) during the austral winter. DPP 81-18005. $149,157.

Stearns, Charles R. University of Wisconsin, Madison, Wisconsin. Collection and analysis of automatic weather station data. DPP 79-25040. $197,689.

Ocean sciences

DeMaster, David J. North Carolina State University, Raleigh, North Carolina. Chronometry and geochemistry of siliceous sediments. DPP 81-17044. $55,962.

Dick, Henry. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. Petrology and geochemistry of the crust and upper mantle between 30°W and 30°E. DPP 80-19769. $80,116.

Fanning, Kent A. University of South Florida, Tampa, Florida. Plankton and the marine geochemistry of radium, germanium, and barium. DPP 82-14213. $48,870.

Hayes, Dennis E. Lamont-Doherty Geological Observatory, Palisades, New York. Regional synthesis of marine geological and geophysical data. DPP 82-00239. $105,515.

Jacobs, Stanley S. Lamont-Doherty Geological Observatory, Palisades, New York. Ross Sea heat flux experiment. DPP 81-19863. $56,000 ($86,000).

Kennett, James P. University of Rhode Island, Narragansett, Rhode Island. Paleoenvironmental evolution based on deep-drilled sedimentary sequences. DPP 81-12615. $59,200.

Marra, John. Lamont-Doherty Geological Observatory, Palisades, New York. Weddell Sea polynya in winter—plankton distribution. DPP 80-08011. $90,349.

Pillsbury, R. D. Oregon State University, Corvallis, Oregon. Ross Sea heat flux experiment. DPP 81-20677. $144,900.

Williams, Douglas F. University of South Carolina, Columbia, South Carolina. Late Cenozoic paleoceanographic studies of deep-sea sediments. DPP 80-23696. $55,845.

Wogman, Nedwin A. Battelle Memorial Institute, Richland, Washington. Air sampling program on USCGC *Glacier*. DPP 82-15008. Support only.

Support and services

Brown, Arthur J. ITT/Antarctic Services, Inc., Paramus, New Jersey. Support of the United States Antarctic Research Program. DPP 80-03801. $858,613. (Partial-year funding).

Cook, J.W., Department of Navy, Washington, D.C. Engineering support for a new staging facility at Christchurch, New Zealand. DPP 82-13765. $65,562.

NSF photo by Russ Kinne

During a heavy snow storm in January 1982, a Delta 2 moves along the ice road between McMurdo Station and Williams Field.

Hart, Pembroke J. National Academy of Sciences, Washington, D.C. Support of the Geophysics Research Board (GRB) and the Committee on Solar-Terrestrial Research (CSTR). ATM 81-22148. $2,750 ($76,500).

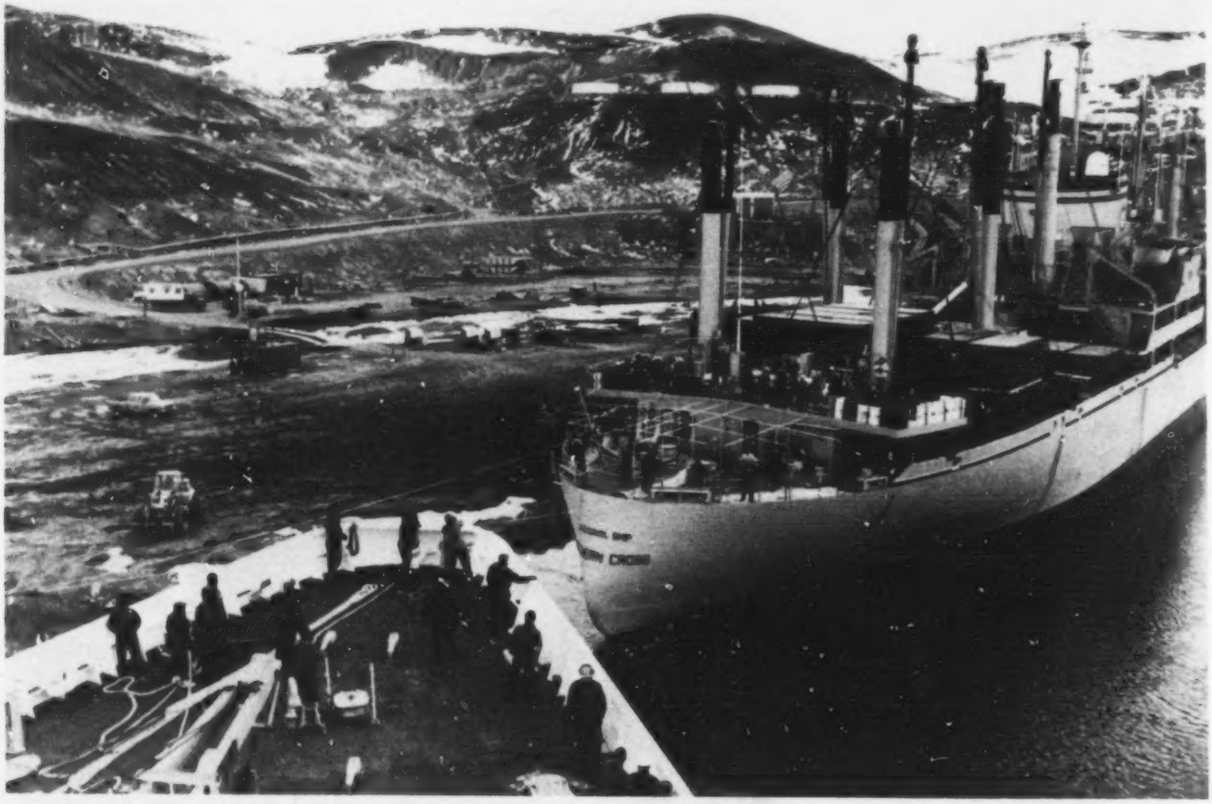
Spilhaus, A. F. American Geophysical Union, Washington, D.C. Publication of the *Antarctic Research Series*. DPP 80-19997. $60,000.

Shoemaker, Brian H. Department of Defense, Washington, D.C. Procurement of aircraft components. DPP 76-10886. $467,102.

Shoemaker, Brian H. Department of Defense, Washington, D.C. Logistics for the U.S. Antarctic Program. DPP 76-10886. $1,900,000. (Partial-year funding).

Thuronyi, Geza T. Library of Congress, Washington, D.C. Abstracting and indexing service for *Current Antarctic Literature*. DPP 70-01013. $143,067.

Varner, Sherrell E. Blue Pencil Group Inc., Reston, Virginia. Editorial services for the annual review issue of the *Antarctic Journal of the United States*. DPP 82-17792. $11,466.



NSF photo by Russ Kinne.

On 14 February 1982 the U.S. Coast Guard icebreaker Polar Sea (foreground) helped the USNS Southern Cross from the ice wharf near McMurdo Station. The Southern Cross delivered supplies on its annual visit to the station and took on cargo to be returned to the United States.

Weather at U.S. stations

Feature	August 1982				September 1982				October 1982			
	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole
Average temperature (°C)	-23.1	- 7.9	-31.5	-61.3	-26.9	- 7.9	-33.0	-61.7	-19.5	- 5.5	-26.3	-49.0
Temperature maximum (°C) (date)	- 9.1 (11)	2.0 (4)	-14.5 (12)	-38.4 (9)	-14.1 (30)	3.6 (30)	- 9.8 (26)	-34.8 (28)	- 4.1 (29)	- 5.3 (1)	- 9.8 (31)	-30.9 (31)
Temperature minimum (°C) (date)	-39.4 (3)	-22.0 (22)	-50.0 (1)	-75.0 (24)	38.6 (5)	-25.8 (8)	-46.2 (2)	-75.4 (13)	-33.0 (7)	-23.3 (7)	-40.2 (5)	-64.0 (3)
Average station pressure (mb)	977.0	994.1	859.1	672.5	978.3	990.6	873.2	670.5	981.1	983.7	855.6	676.6
Pressure maximum (mb) (date)	994.9 (31)	1016.0 (14)	877.2 (8)b	681.9 (10)	998.0 (4)	1026.6 (26)	875.5 (25)	684.8 (19)	992.1 (15)	1010.1 (12)	874.8 (10)	694.3 (9)
Pressure minimum (mb) (date)	958.7 (16)	964.0 (31)	835.1 (27)	653.8 (25)	957.3 (30)	949.3 (5)	834.5 (5)	658.1 (13)	959.4 (1)	948.1 (27)	838.2 (3)	659.5 (13)
Snowfall (mm)	33.1	a	152.4	Trace	91.4	a	193	Trace	94.2	a	165.1	Trace
Prevailing wind direction	090°	a	220°	045°	090°	a	200°	045°	090°	045°	170°	045°
Average wind (m/sec)	3.2	5.1	5.1	4.9	4.9	4.7	3.9	4.6	2.5	3.6	4.6	6.3
Fastest wind (m/sec) (date)	33.1 140° (4)	31.7 a (2)	21.9 230° (25)	15.4 360° (7)	22.4 080° (18)	35.3 a (4)	21.1 160° (19)	15.9 315° (27)	14.3 170° (2)	26.4 a (1)	20.4 360° (31)	21.1 315° (29)c
Average sky cover	7.6	6.6/10	4.8	4.7	6.5	8.3/10	5.5	3.6	6.6	7.4/10	6.8	6.6
Number clear days	4	5.5	14.75	17.3	2	0	10	18.7	5	1.3	7	9.9
Number partly cloudy days	7	8.1	1.5	2.1	9	10.8	3.5	5.4	12	14.7	3.75	2.5
Number cloudy days	20	17.4	14.75	11.6	19	19.2	16.5	5.9	14	15	20.25	18.6
Number days with visibility less than 0.4 km.	3.3	a	14.0	0.5	.6	a	10.0	4.0	0.8	a	12	4.5

Prepared from information received by teletype from the stations. Locations: McMurdo 77°51'S 166°40'E, Palmer 64°46'S 64°3'W, Siple 75°55'S 83°55'W, Amundsen-Scott South Pole 90°S. Elevations: McMurdo sea level, Palmer sea level, Siple 1054 meters, Amundsen-Scott South Pole 2835 meters. For prior data and daily logs, contact National Climate Center, Asheville, North Carolina 28801.

a. Data not available.

b. Also on 10 August 1982.

c. Also on 8 and 10 October 1982.

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A Navy UH-1N helicopter delivers supplies to University of Illinois biologists camped in January 1982 on one of the Dailey Islands (77°53'S 165°8'E) at the southern end of McMurdo Sound. The scientists protect their gear from the downdraft created as the helicopter lands.

NSF photo by Russ Kinne.

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Cover. In the Bowers Mountains (71°10'S 163°15'E), northern Victoria Land, a geologist from Western Washington University checks equipment on a sledge. In the background other members of the party collect rock cores with a diamond-bit coring drill, lubricated by a mixture of water, oil, and alcohol. The cores provide information on the region's tectonic history, particularly its position before the breakup of Gondwanaland. Two papers bas on this study appear on pages 8 through 10 of this issue. (NSF photo by Russ Kinne.)

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U.S. Antarctic Research Program, 1981–1982

The United States maintains an active research program in Antarctica and the surrounding seas and employs ships, aircraft, and military and civilian personnel for operations and support. The National Science Foundation plans, funds, and manages the program, including support. Logistics are provided by the U.S. Navy, the U.S. Coast Guard, and by a civilian contractor (ITT Antarctic Services, Inc.).

As a part of the U.S. Antarctic Research Program scientists from universities and colleges, private organizations, and Federal agencies study problems of global and regional significance. The scope of this work is illustrated by the 160 reports in this *Antarctic Journal of the United States*. These papers, prepared by program participants, describe field work during 1981–1982, preliminary analyses of data, studies of data acquired earlier, and the activities of supporting organizations in the field and in the United States. The assistance of the principal investigators and project directors is gratefully acknowledged.

Science highlights. In February 1982 U.S. geologists and paleontologists, investigating Seymour Island (64°17'S 56°45'W) near the tip of the Antarctic Peninsula, discovered the fossils of a land mammal, the first ever found in Antarctica. These fossils of a small, rodent-like marsupial that most closely resemble the genus *Polydolops* clearly suggest the presence of a former land connection—or a series of close islands separated by shallow water—between the peninsula and South America. Because marsupials have existed only in the Americas and Australia, scientists presumed that Antarctica was a land bridge between the two regions. This fossil find not only confirms these theories but also further supports the theory that Antarctica along with other southern continents once formed the supercontinent Gondwana. Earlier discoveries, elsewhere in Antarctica, of Permian age rocks bearing the fossil leaf *Glossopteris* and of an upper jaw section of a small, four-legged reptile *Lystrosaurus* have provided strong evidence that Antarctica and the other continents had been joined as early as 270 million years ago and as late as 230 million years ago, because both finds could be related to discoveries on other continents. The 1982 find indicates that the Antarctic Peninsula and South America were connected between the late Paleocene (when polydolopids first are known to have existed in South America) and the late Eocene (when they are now known in Antarctica)—55 to 40 million years ago.

Geologists also found other fossils on Seymour Island, which contains a rich record of life in the Southern Hemisphere during the late Cretaceous and early Tertiary (from 100 million to 30 million years ago). These included the first discovery of Tertiary reptiles (lizards), Cretaceous bony fishes (holosteans), and a Tertiary coal seam. Fossils of at least two Cretaceous plesiosaurs (marine reptiles) were found—one about 25 feet long, and the other approximately 50 feet long, as well as several small Cretaceous mososaurs (marine reptiles).

Along the Antarctic Peninsula, marine biologists continued studying the crustacean krill. Although underwater observations are critical to an accurate understanding of krill behavior and biology, opportunities to observe krill schools directly are rare, and data have accumulated slowly. During 1981–1982 biologists found that at distances of one to two meters divers could easily collect data on density, orientation, swimming speed, school size and shape, interactions among individuals within the schools, feeding, molting, excretion, and reaction to predators. Other biologists, studying the spawning behavior of krill, found that brood sizes vary greatly and are not closely linked to the size of the female. Preliminary data analyses show that each brood consists of 1,000 to 6,000 eggs with a median size of 2,000 eggs. Assuming that 6 days elapse between broods and the spawning season lasts 2 months, biologists estimate that a single krill may release about 20,000 eggs in a season. This is 5 to 10 times greater than previous estimates made by investigators who worked with frozen or preserved animals. Another group found that egg-bearing females cannot withstand pressures exceeding 25 atmospheres (the equivalent of 250 meters); consequently, spawning must occur near the surface.

In the Weddell Sea 13 U.S. and 13 Soviet marine scientists gathered the first comprehensive data from within the winter sea ice surrounding Antarctica. On 20 October 1981 the Soviet icebreaker *Mikhail Somov* with the U.S.-Soviet expedition aboard entered the pack ice about 1,600 kilometers off Queen Maud Land and for 2 weeks pushed southward through ice until it reached a point 885 kilometers from Antarctica, where it turned and headed for open ocean. The investigators were organized into teams to study physical oceanography, chemistry, biology, sea ice, meteorology, and sound velocity in the ocean. The ship stopped 37 times for scientific work; underway observations were also made.

One objective was to locate a polynya, an ice-free "lake" that appears and disappears in the frozen pack ice. Since 1973 satellite data have located polynyas in the Weddell Sea during the late austral winter. Because of the extreme difficulty of entering this region during the maximum extent of the pack ice, marine scientists have not been able to observe this phenomenon directly. Although a polynya did not appear during the voyage, the scientists did discover intense, 12-mile-wide eddies of relatively warm water that may contribute to the formation of polynyas. Extending into the surface layers, these eddies can bring large amounts of heat in contact with the atmosphere.

Zooplankton collected during the cruise showed a dramatic difference in both biomass and abundance between the ice edge and the pack ice. Abundance under the pack ice was 3 to 5 individuals per cubic meter, while at the edge it was 25 to 42 individuals per cubic meter. The greater abundance at the ice edge appears to be due to melting that stabilizes the surface water layers. The scientists also found that wave heights greater than 0.25 meter generate effects that penetrated 120 nautical miles into the ice pack, twice the predicted distance. These are the remnants of long, high swells at the ice edge and are characteristic of the long fetch and high winds of the southern ocean.

In East Antarctica at Dome C (75°S 124°E), U.S. and French glaciologists continued their investigation of the ice sheet. U.S.

scientists measured electromagnetic wave velocity in the firn (the transitional stage between snow and glacier ice), conducted sonic logging and seismic shooting in a 900-meter borehole (drilled by French investigators in 1979), searched for seismic reflectors deep within the ice sheet, and tested new radar recording equipment. They also remeasured a strain network to record the ice sheet's movement since 1979, took temperature profiles of the ice sheet, and continued studies of firn stratigraphy to determine what annual changes affect the ice sheet's near-surface structure. French glaciologists tested a special boring device and thermal probe used to sample ice at various depths. This season drilling reached a depth of only 235 meters into the ice sheet, but the goal is to drill 2,000 meters deep to study climate changes over the last 125,000 years. From the ice surface and the 900-meter hole they also took samples, which made possible reconstruction of recent and long-term (up to 30,000 years ago) changes in the Earth's environment.

At the South Pole scientists measured the amounts of carbon dioxide, fluorocarbons, and methyl chloroform (anthropogenic trace gases existing in the atmosphere). Gases containing chlorine or bromine may deplete the stratospheric ozone layer and allow more ultraviolet radiation to reach the Earth's surface. For the last 8 years one group has gathered information on these long-lived gases to determine how much has accumulated and how they are modifying the Earth's atmosphere. They found that these gases, which are released by industrial processes and other human activities, exist at the South Pole in concentrations not much less than those in some areas of the Northern Hemisphere. Since 1975 concentrations of two fluorocarbons (F-11 and F-12) and methyl chloroform have not changed significantly. Although emissions of these three gases into the atmosphere may no longer be increasing, two other rare fluorocarbons (F-22 and F-113) are increasing rapidly. Measurements of F-22 and F-113 have been taken at the South Pole and the U.S. Pacific Northwest since 1979, but less is known about the global sources and lifetimes of these gases than is known about F-11 and F-12.

At a camp near the Canham Glacier (72°12′S 163°50′E) in northern Victoria Land, researchers from the United States, New Zealand, Australia, and West Germany participated in 22 projects focused on the region's tectonic development from the Precambrian (over 600 million years ago) up to geologically recent vulcanism (in the last few thousand years). By using motor toboggans and three UH-1N helicopters, scientists were able to investigate particular sites within a 100-nautical-mile (185-kilometer) radius of the camp. This area extended to the polar plateau on the west, the sea on the north and south, and almost to Hallett Station (72°19′S 170°13′E) on the east. One objective of the expedition was to provide information for more accurate geologic maps. Twelve maps in the 1:250,000 Antarctic Geological Reconnaissance Series will be produced by combining new data with previously acquired information. Other investigations included studies of present and past glaciation, a biological investigation of lichens living beneath the surface of rocks, and a gravity and airborne-radiometric survey. During the radiometric survey, geologists found that the average radioactivity of the rocks exposed in northern Victoria Land is roughly twice the level of outcrop radioactivity in the Darwin Glacier area, where previous surveys have been conducted. This difference, related partly to the geology of these widely separated portions of the Transantarctic Mountains, may also reflect fundamental differences in the abundance of radioactive elements in the Earth's crust and mantle.

In northern and southern Victoria Land field parties collected 378 meteorite fragments. These were added to 805 fragments collected in Antarctica by U.S. geologists since 1976. One of these samples has drawn special attention from the scientific community. Several different groups, using sophisticated geochemical analyses, have determined this 2.54-centimeter, 31.4-gram fragment to be from the moon. Preliminary analyses have shown that the sample is composed primarily of the mineral anorthosite, a plagioclase feldspar, in a glassy matrix and that the unusual light green color of its crust is due to its low iron content.

1981–1982 austral summer operations and support. Between August 1981 and March 1982, 264 investigators conducted 80 projects on the continent and in the surrounding waters. Foreign participation in the 1981–1982 program included 47 researchers from 19 countries. Land-based research was conducted at the four U.S. stations (McMurdo, Amundsen-Scott South Pole, Siple, and Palmer), from camps in northern Victoria Land and at Dome C in East Antarctica, from smaller field camps, and at stations of other nations. Marine research was conducted from the Foundation's research ship *Hero*, the Coast Guard icebreakers *Polar Sea* and *Glacier*, and the Soviet research ship *Mikhail Somov*. Logistics and support in Antarctica were provided by 1,328 U.S. Navy and other military personnel (including ships' personnel) and 215 employees of a contractor—ITT Antarctic Services, Inc. (ANS).

Between 20 and 24 August 1981, three ski-equipped Hercules airplanes (LC-130s) made six flights between Christchurch, New Zealand, and McMurdo Station to end the winter's isolation that had begun the previous February. These flights brought 194 scientists and support personnel, adding to McMurdo Station's 93 wintering personnel, to begin early season projects and prepare for the austral summer. On 9 October 1981 the major deployment of scientific and support personnel began. Twenty-six flights by U.S. Military Airlift Command C-141 wheeled airplanes, 10 flights by Royal New Zealand Air Force C-130 airplanes, and 4 flights by Royal Australian Air Force C-130 airplanes augmented U.S. Navy LC-130 flights in transporting personnel and priority equipment between Christchurch and McMurdo Station's sea-ice runway until 17 December, when LC-130 operations shifted to the Williams Field skiway on the Ross Ice Shelf.

During the austral summer Navy pilots and crews flew six LC-130 airplanes 3,539 hours to bring personnel and equipment to U.S. stations and support science in remote areas. They flew seven UH-1N helicopters 1,541 hours to support science near McMurdo Station and in northern Victoria Land. Between October 1982 and February 1983, these aircraft transported 2,252 passengers, 2.8 million pounds of cargo, and 463,000 pounds of fuel products. Navy aircrews also provided assistance to a West German expedition, whose research ship the *Gotland II* was crushed by the pack ice and sank, and evacuated the expedition via the U.S. field camp in northern Victoria Land, McMurdo Station, and Christchurch, New Zealand. Other Navy logistics included operation of a cargo ship (USNS *Southern Cross*) and a tanker (USNS *Yukon*), which resupplied McMurdo Station in January.

The U.S. Coast Guard operated the two icebreakers, *Polar Sea* and *Glacier*, each with two helicopters. *Polar Sea* took supplies and personnel to Palmer Station in early January. Later that month at McMurdo Station the icebreaker opened a 23-mile long channel in McMurdo Sound ice for the resupply ship and tanker. Before returning to the United States *Polar Sea* supported science projects in the Ross Sea. *Glacier* supported science projects in the Ross Sea, tended the McMurdo Sound channel, and assisted the cargo ships during January until it departed for Palmer Station. The icebreaker also supported science projects in the Antarctic Peninsula area. In March *Glacier* called at Palmer to pick up scientific equipment and specimens for return to the United States.

Six hundred and fifty-one members of the Naval Support Force operated much of McMurdo Station, provided health services and long-range communications, and planned and coordinated Navy and Coast Guard logistics. Near McMurdo Station the Navy public works department installed a scissoring bridge to improve travel between the shore and the annual sea ice. This bridge is lightweight and has an 18.3-meter span that can support 60 ton loads. Other Navy public works activities included replacing the wooden-floored Jamesway huts at Byrd surface camp (80°01'S 119°32'W), the refueling stop between McMurdo and Siple Stations. The new camp comprises six 3.7-meter by 7.3-meter modules atop 10-ton sleds.

During the austral summer 103 science personnel conducted research at and near McMurdo Station. In addition to support by military personnel, 150 government and contractor (ANS) employees were based at McMurdo and supported research there and at inland stations. At McMurdo Station ANS employees performed construction and support and managed scientific laboratories and Williams Field. Construction projects included completing site preparations for the new McMurdo Station water distillation plant.

Contractor employees operated South Pole, Siple, and Palmer Stations, the R/V *Hero*, and field camps in northern Victoria Land and at Dome C. In early November Amundsen-Scott South Pole Station began summer operations during which 48 researchers were supported by 22 ANS employees and 2 Navy personnel. Construction included erecting a very-low-frequency ionosonde antenna tower and raising the platform of the cosmic ray research building.

Siple Station, closed during the 1981 winter, was reopened in November 1981. During the austral summer at Siple, nine scientists were supported by nine ANS employees and a Navy corpsman. ANS employees installed a satellite-tracking radar pedestal and antenna and erected the VLF dipole ionosonde antenna at Siple Station.

Large temporary camps in northern Victoria Land and at Dome C enabled scientists to work in remote areas. In late October and early November ANS employees set up the northern Victoria Land camp at the north end of Evans Névé near the head of the Canham Glacier. Between 9 November 1981 and 13 January 1982 63 scientists and technicians from the United States and other nations participated in 22 projects based at that camp. Six ANS employees, 15 Navy helicopter crew members, and one Navy corpsman provided support. The Dome C camp, previously used during the 1979–1980 austral summer, was occupied between 20 November 1981 and 28 January 1982. At Dome C 15 U.S. and French glaciologists were supported by four ANS employees and one Navy corpsman.

Antarctic Peninsula operations began in early October, when U.S. biologists studying penguin behavior and ecology arrived at King George Island aboard a Chilean C-130 airplane to work at the Polish station Arctowski. In early December the R/V *Hero* brought the 1982–1983 relief crew and the first researchers to Palmer Station. During the austral summer 34 scientists, based at Palmer Station, conducted research in the Peninsula region. Support was provided by 11 ANS employees and a Navy corpsman; 13 ANS employees operated the R/V *Hero* during the season.

Winter operations began at Siple and South Pole Stations in early February 1982 and at McMurdo Station in late February. Summer operations in the Antarctic Peninsula area continued until early April 1982.

Support in the United States. In the United States the marine sediment core facility at Florida State University distributed 4,367 samples, collected during 44 cruises by 4 ships, to 26 investigators at 17 institutions in Australia, France, India, the Soviet Union, and the United States. Three-hundred and one meters of new piston, trigger, and hydrocast cores and 149 grab samples recovered during 1981–1982 USCGC *Glacier* cruises near the Antarctic Peninsula and South Shetland Islands were received and processed.

At the Smithsonian Oceanographic Sorting Center the staff processed 1.3 million specimens and recorded them in the facility's computer data base. From the sorted collection they distributed 900,000 specimens in 9,700 lots from over 7,000 samples to specialists for analyses.

One hundred meteorite fragments collected during 1980–1981 were classified by researchers at the Smithsonian Institution's Department of Mineral Science. As of September 1982 the National Aeronautics and Space Administration's Johnson Space Center distributed 1,770 meteorite samples to 110 research groups or investigators in the United States and 12 other countries.

Ice core samples were distributed from a facility at the State University of New York at Buffalo.

The Library of Congress continued to abstract and index literature for the *Antarctic Bibliography*. To date more than 26,000 bibliographic entries have been published and made available for on-line searching through the System Development Corporation's ORBIT system.

Policy. On 5 February 1982 the President of the United States issued a memorandum to 14 executive agencies to announce that the U.S. Antarctic Program will be "maintained at a level providing an active and influential presence in Antarctica designed to support the range of U.S. antarctic interests." The memorandum was prepared following a review of the program by the Antarctic Policy Group, an interagency committee chaired by the Department of State. The group recommended a balanced research program as the best expression of U.S. antarctic interests. In his memorandum the President supported this analysis and directed the National Science Foundation to continue to budget for and manage the program. As outlined by the President, the U.S. program will include research in major disciplines and the use of year-round stations at the South Pole and two coastal locations.

On 7 April 1982, the Convention on the Conservation of Antarctic Marine Living Resources entered into force. The convention, signed by 15 nations in May 1980, establishes a conservation standard to ensure the continued health of the antarctic marine ecosystem and defines rational use of the system's resources as actions that will not disturb the ecosystem's balance. The standard applies not only to the Antarctic Treaty area (south of 60° South latitude) but also to the area between 60°S and the Antarctic Convergence. Ratification by eight nations was necessary before the convention could enter into force. In

February 1982 the United States became the seventh ratifying nation, when the President signed the U.S. instrument of ratification. New Zealand made the decisive eighth ratification in March 1982. The six nations that ratified the convention in 1981 are Australia, Japan, the Soviet Union, Chile, South Africa, and the United Kingdom (all consultative parties to the Antarctic Treaty). Upon ratification, each nation became a contracting party to the convention.

To carry out the terms of the convention a commission and a scientific committee were established. The two groups met for the first time between 25 May and 11 June 1982 in Hobart, Australia. Australia, Chile, the European Economic Community, the German Democratic Republic, the Federal Republic of Germany, Japan, New Zealand, South Africa, the Soviet Union, the United Kingdom, and the United States participated; representatives of the remaining convention signatories (Argentina, Belgium, France, Norway, and Poland) attended as observers. The Commission and Scientific Committee meetings focused on initial operating procedures. For the commission the participants agreed on financial and staff regulations, the appointment of a Secretary General, and budgets for 1982 and 1983. The 1982 budget was set at approximately $400,000 (U.S. dollar equivalent); the 1983 budget is $620,000 (U.S. dollar equivalent). Although the scientific committee did not reach a final agreement on procedures, they did discuss the establishment of a data management system and ways of reporting fisheries catches and other necessary data.

In June 1982 the 14 Antarctic Treaty consultative parties met in Wellington, New Zealand, for a Special Consultative Meeting on Antarctic Mineral Resources, in accordance with Recommendation XI-1 of the Eleventh Antarctic Treaty Consultative Meeting. The Wellington meeting represented a transition from defining a common commitment to develop a regime to elaborating the regime's specific provisions. The United States, Australia, Argentina, New Zealand, and the United Kingdom presented papers illustrating conceptual approaches to developing a regime. The U.S. outline addressed specific issues to provide a clear picture of a system that would make possible rational decisions about future mineral resource activities. Discussions of these proposals helped define and clarify issues to be addressed during the future negotiations. The representatives agreed on an outline of subject areas to be discussed in developing the regime. A second session was held in Wellington in January 1983; the next session, planned for July 1983, will be held in the Federal Republic of Germany.

Budget. Fiscal 1982 support of the U.S. antarctic program, provided through the National Science Foundation, totalled $68,504,786 in the following major categories:

- grants to institutions for scientific projects in atmospheric sciences $1,945,961, biological sciences $2,188,223, earth sciences $1,348,000, glaciology $1,025,669, ocean sciences $1,303,169, information and advisory services $686,662, and direct science support (costs normally included in a grant for work at an institution but provided in Antarctica from program resources) $10,100,000—$18,597,684 total science support;
- construction and procurement $7,100,000;
- other logistic support $42,807,102.

This aerial view of the sea ice off Cape Evans, Ross Island, was taken in early January 1968, when the sea ice was deteriorating. (U. S. Navy photo, XAM-80582-1-68, by Jackie W. Richards.)

Terrestrial geology and geophysics

Geochronologic studies in East Antarctica: Age of pegmatites in Casey Bay, Enderby Land

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The Napier Complex of Enderby Land is an Archean granulite-facies terrain bounded and intersected by zones metamorphosed and deformed in the Late Proterozoic about 1,000 million years ago (Rayner Complex) and the Early Paleozoic 500 million years ago (DePaolo et al. in press; Grew and Manton 1979; James and Black 1981; Ravich and Kamenev 1975; Sheraton et al. 1980). Available data indicate that the precursors of the Napier Complex metamorphics may be as old as 3,500 million years and have been affected by several deformational, metamorphic, and plutonic events between 3,000 and 2,500 million years ago. However, there is considerable debate regarding not only the relative timings of these events, but also the extent of the areas affected by post-Archean events.

The islands in the eastern part of Casey Bay lie in one of the problematic areas. Ravich and Kamenev (1975), Sheraton and associates (1980), and James and Black (1981) map these islands in the transition zone between the Rayner and Napier Complexes. However, mineral assemblages in pelitic rocks in Casey Bay, such as sapphirine-quartz, and undeformed mafic dikes suggest that the islands in Casey Bay are composed of Napier Complex rocks little affected by post-Archean events. Post-Archean activity is restricted to discrete zones of intense deformation, retrograde metamorphism, and pegmatite emplacement.

We report here uranium-lead data on zircons collected during the 1979–80 austral summer from two pegmatites in Casey Bay: Sandiford locality R25730 on McIntyre Island (67°22'S 49°05'E) and Grew locality 2233 on an unnamed rocky point about 2 kilometers south of McIntyre Island ("Zircon Point" in Grew 1981). The sampled pegmatites (early generation of Grew 1981) appear to be coeval with the granulite-facies metamorphism and associated deformation. The beryllium-bearing minerals chrysoberyl, taaffeite, and surinamite are found in a similar pegmatite at locality 2234 (250 meters south of locality 2233) and in a second one on an unnamed island 5 kilometers west-southwest of McIntyre Island (Grew 1981).

Pegmatites at locality 2233 form discordant pods up to 1 meter thick in a garnetiferous gneiss. The pods trend N30°E and consist of quartz and feldspar, with accessory garnet, magnetite, monazite, and zircon. The pegmatite at R25730 is an irregular pod up to 0.5 meter across formed in the pressure shadows between boudins of garnet-feldspar-sillimanite gneiss. The pegmatite consists of mesoperthite, quartz, garnet, and accessory rutile, zircon, and monazite. The boudins and associated pegmatites formed during the D_2 structural event (terminology of James and Black 1981). The only apparent effect of post-D_2 deformation is recrystallization of some feldspar and quartz grain boundaries. Sapphirine occurs with quartz in other D_2 pegmatites nearby and in the host gneisses, indicating that the sapphirine-quartz association was stable during the D_2 structural event. Consequently, the D_2 structural event and associated pegmatites were coeval with the peak of metamorphism in Casey Bay.

The analyzed zircons are euhedral or subhedral and one to several millimeters across. They were crushed and any surface contamination was removed before analysis by standard techniques for uranium and lead isotopes (table). Lead isotope ratios corrected for a 2,500-million-year lead are plotted in the figure. The data for three zircons from locality R25730 are nearly concordant at 2,500 million years, while the data for two zircons from locality 2233 lie close to a chord intersecting concordia at 2,500 and 1,000 million years. We conclude that the zircons and pegmatites at both localities crystallized 2,500 million years ago and thus are coeval with the 2,500-million-year-old pegmatites from other parts of the Napier Complex dated by Grew and Manton (1979). Moreover, the two pegmatites containing beryllium minerals, which are similar in structural relations to the sampled pegmatites, most likely are also 2,500 million years old.

Our zircon data provide a well-constrained age of 2,500 million years for the D_2 structural event and peak of the granulite-facies metamorphism in Casey Bay. This age assignment is consistent with the 2,500-million-year age assigned to the granulite-facies metamorphism of the Napier Complex by Grew and Manton (1979) and by DePaolo and associates (1982). In contrast, James and Black (1981) suggest an approximate 3,000-million-year age for D_1 and D_2 and the peak metamorphic conditions.

Uranium (U) and lead (Pb) contents of zircons from pegmatites on McIntyre Island (locality R25730) and on a nearby point (locality 2233) in Casey Bay, East Antarctica

Sample	U (ppm)[a]	Pb (ppm)[a]	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{206}Pb/^{208}Pb$	$^{207}Pb^b/^{235}U$	$^{206}Pb^b/^{238}U$
2233a	3,023	1,278	4.0×10^4	6.393	59.49	9.017	0.4189
b	1,168	538.8	3.2×10^4	6.291	12.56	9.461	0.4326
R25730a	2,265	1,071	2.3×10^4	6.175	33.01	10.29	0.4610
b	3,327	1,575	$> 5 \times 10^4$	6.148	48.38	10.44	0.4654
c	3,400	1,579	$> 5 \times 10^4$	6.156	49.26	10.23	0.4568

[a] Parts per million.

[b] Radiogenic component.

They assign the 2,500-million-year age to D_3 and a later metamorphism.

The lower intercept of 1,000 million years suggests lead loss about 1,000 million years ago. This is the first evidence within the Napier Complex for a Late Proterozoic event coeval with the Rayner event. Further east in Enderby Land, isotopic data lie on a 2,500–600-million-year chord, indicating an Early Paleozoic event (Grew and Manton 1979). Heating related to the discrete shear zones may have caused the lead loss 1,000 million years ago in the Casey Bay zircons. We plan to analyze more zircons from locality 2233 to better constrain the age of lead loss at this locality.

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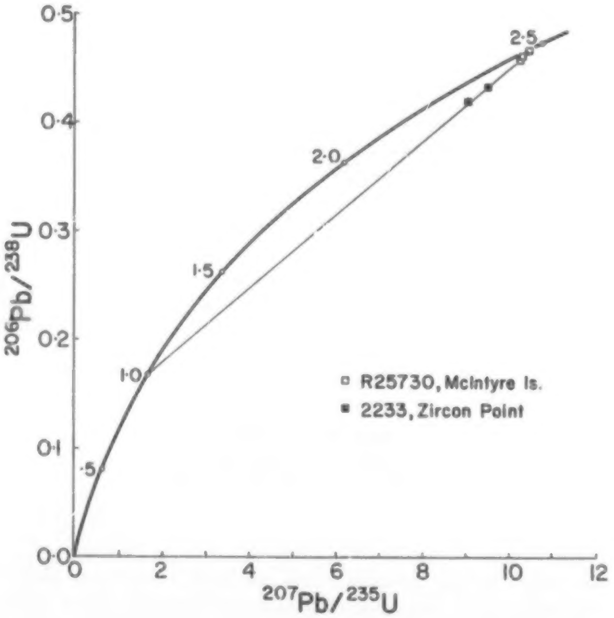

Concordia diagram for zircons from pegmatites on "Zircon Point" and McIntyre Island, Casey Bay, East Antarctica. Pb = lead; U = uranium.

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Northern Victoria Land Project, 1981–1982

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The Northern Victoria Land Project was conducted during the 1981–82 austral summer from a remote, helicopter-based field camp at the north end of Evans Névé near the head of Canham Glacier (72°12′S 163°50′E; approximately 1,700 meters above sea level). The camp was centrally located so that the area investigated extended to the polar plateau on the west, the seacoast to the north and south, and nearly as far as Hallett Station to the east. These limits were dictated by the flying range (185 kilometers, or 100-nautical-mile radius) of the three UH-1N ("Huey") helicopters that provided support for the scientists.

The first LC-130 flight to the camp to begin construction was on 24 October. Construction was under the direction of Allan Priddy and other employees of ITT Antarctic Services, Inc. P. V. Colbert was the ITT camp manager for the season. The camp was ready for occupancy by 5 November, when the three helicopters flew there from McMurdo Station, about 600 kilometers to the south. The first contingent of scientists arrived the next day, and flight operations for science projects began on 9 November.

Northern Victoria Land camp, or NVL as it was called, was nearly identical in design and construction to the last four helicopter-supported remote camps of previous seasons, consisting of five Jamesway buildings and a plywood generator hut. Details of camp construction and logistic support for these camps have been discussed previously (Splettstoesser and Turner 1982; Splettstoesser and Webers 1980; Splettstoesser, Webers, and Waldrip 1982). About 2 weeks normally are required to construct these camps, and as many as 45 LC-130 flights are required to transport construction material, personnel, fuel, and supplies to the camp and to retrograde the camp to McMurdo Station at the end of the season. Sixty-eight LC-130 flights were required for the NVL operation, compared with 43 for Ellsworth in 1979–80 (Splettstoesser, Webers, and Waldrip 1982). Although Ellsworth camp was considerably farther from McMurdo (2,000 kilometers) than was NVL, there were fewer personnel involved, the camp was at a lower elevation (1,250 meters), one of the buildings at Ellsworth was not returned to McMurdo, and the Ellsworth season was shorter by about a month.

Chief scientist for the NVL operation was E. Stump, who determined the scientific priorities for all support conducted from the camp. Flight schedules were made up daily by J. Splettstoesser in consultation with the helicopter pilots and the principal investigators. During Splettstoesser's absence from late November to mid-December, Garry D. McKenzie of the National Science Foundation's Division of Polar Programs coordinated these activities. The flying operation was under the command of LCDR G. R. Buford until 15 December, and under LCDR W. B. Manning thereafter. Members of the New Zealand Antarctic Research Program (NZARP) team—Michael Cattley (general field assistant at NVL), Graeme Morgan (cook), and Eric Saxby (field leader and coordinator) of NZARP projects—provided considerable assistance to the NVL operation.

A total of 63 scientists and technicians, more than at any previous camps, participated in the 15 U.S., 5 New Zealand, and 2 Australian science projects. Individual projects were scheduled and phased so that there were no serious buildups of population at NVL. However, after the German Antarctic North Victorialand Expedition (GANOVEX) ship *Gotland II* sank offshore at about 70°21′S 167°31′E on 18 December, all German expeditionary personnel phased through NVL camp during a 10-day period prior to their transport to McMurdo. (At one time during this period, NVL camp population was 71, and an additional 38 were in field camps.) This exercise was handled smoothly and efficiently by all concerned, posing no noticeable problems.

A variety of field operations was conducted from NVL, using both helicopter support and motor toboggans. Motor toboggans were used extensively by many investigators and were particularly an asset when poor weather precluded helicopter operations. Six full days and parts of 6 other days were nonflyable as a result of weather. The helicopters flew a total of 533 hours in support of science projects, second only to the 1978–79 season at Darwin Galcier, when 617 hours were flown. Science operations ceased on 13 January, and two helicopters flew back to McMurdo on 15 January. The third helicopter had experienced engine failure several days previously and was returned to McMurdo in an LC-130 on 15 January. In the only major accident of the season, one helicopter crashed on Mount Jackman on 25 November. No injuries resulted, and the damaged machine was replaced by another from McMurdo. The damaged helicopter was returned to McMurdo on 17 December. In the only other mishaps, one scientist suffered a severely frostbitten hand and another dislocated a shoulder in a fall on a steep slope.

The scientific projects were primary geologic investigations. Each of the spectrum of rock groups in northern Victoria Land was investigated by at least one field party. In addition, there were projects studying present and past glaciation, a gravity survey and an airborne radiometric study, a meteorite search, and a resurveying of previously established topographic stations. The one biology project involved the collection and study of lichens. The individual projects of the U.S. parties are reported elsewhere in this issue.

During the course of investigations it was found that portions of the 1:1,000,000 geological map of northern Victoria Land (Gair et al. 1969) were in error in areas that had been touched on just in passing or where only photointerpretation had been possible. It was found that the Outback Nunataks are mainly metamorphic rocks, similar to those in the Daniels Range, intruded in numerous places by tourmaline-bearing pegmatites. The coastal areas between the Aviator and Borchgrevink Glaciers previously were unvisited. Mapping in this area by several parties showed that the narrow zone of Bowers Supergroup rocks found to the north extends straight through to the coast at the mouth of Mariner Glacier. The coastal area between Mariner and

Borchgrevink Glaciers is underlain largely by lavas and hyaloclastites of the McMurdo volcanics, rather than by granite and Robertson Bay Group, as previously mapped.

Compilations of mapping from this season, along with that of previous workers, will permit the production of 12 maps in the *1:250,000 Antarctic Geological Reconnaissance Series*.

In addition to the scientific program at NVL, the camp hosted several distinguished visitors. Stephen Pyne, National Endowment for the Humanities Fellow, spent several weeks in camp and with field parties chronicling activities, as did Russell Kinney, photographer for the National Science Foundation.

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Study of radioelement concentrations in northern Victoria Land by gamma-ray spectrometry

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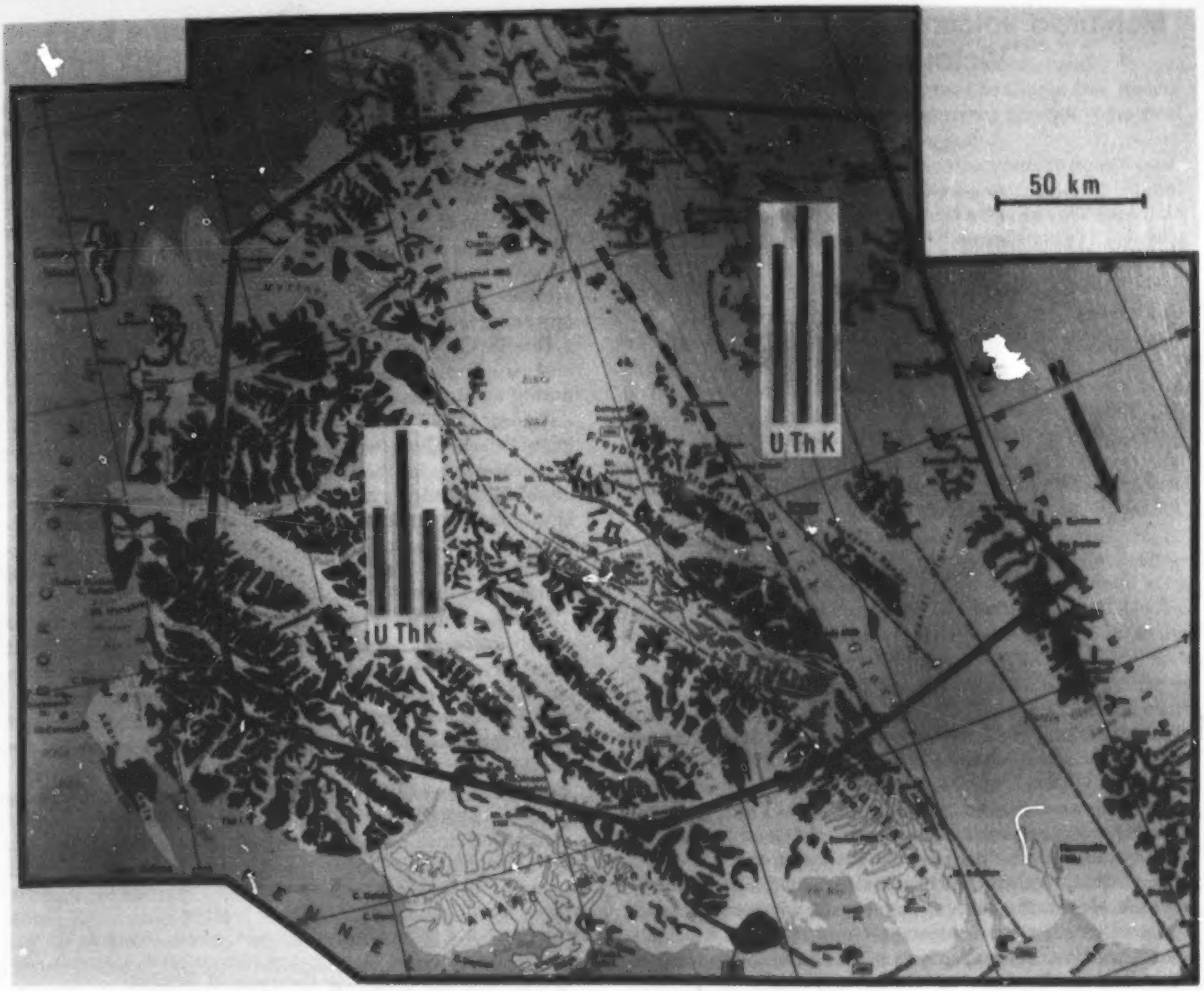
During the 1981–82 field season we conducted airborne radiometric survey operations from the remote camp near the Freyberg Mountains in northern Victoria Land. Survey operations began on 20 December 1981, and a total of 3.260 kilometers of flight line was completed during the season. In addition, we made test flights to calibrate the counter for Compton scattering and attenuation with variable ground clearance. Upon return to McMurdo Station, we made a similar calibration in Taylor Valley. Finally, we emplaced a series of solid state radiation dosimeters at several locations in the Ross Island volcanics. These rocks are known to be unusually high in radioelement concentration (Zeller et al. 1982). The dosimeters will be recovered after 1 year and will furnish the basis for a feasibility test of this method for measuring the geologic radiation environment.

The results of the northern Victoria Land survey have already been evaluated, and they have proved to be especially interesting. The average radioactivity of the rocks exposed in northern Victoria Land is roughly twice the level of outcrop radioactivity in the Darwin Glacier area. While this undoubtedly is related in part to differences in the geology of these widely separated portions of the Transantarctic Mountains, it also may reflect fundamental differences in the crustal abundance of the radioelements.

To facilitate data interpretation, the survey area was divided into two major districts separated by the Rennick Glacier and the major fault that parallels its eastern margin. The division is based on the general geology of northern Victoria Land. Significant differences characterize the two districts (Dreschhoff, Zeller, and Kropp 1982). The figure shows the area surveyed and provides a graphic summary of the results. The data are reported as relative values by relating all individual radioelement concentrations to the corresponding mean concentration for the entire survey area. The two bar graphs represent the maximum relative values for the largest anomalies of uranium, thorium, and potassium in the individual districts and are derived by averaging the points that exceed two standard deviations from the mean for the entire area. The shaded length of the bar represents the relative mean for the entire area.

The northeastern district shows mainly concentrations of thorium but little anomalous enrichment of uranium. In contrast, the southwestern district exhibits anomalous concentrations of all three radioactive elements, and most of the anomalies are associated with the Granite Harbor Intrusives or the Kukri Erosion Surface where it cuts the Granite Harbor plutons. One of the strongest anomalies occurs at the top of Mount Bower in the Outback Nunataks where a remnant of the Beacon Group resting on the Kukri Erosion Surface is preserved. A landing was made, but high winds prevented a thorough evaluation of the outcrop. However, the thorium-to-uranium ratio indicates that geochemical separation of these elements has occurred and that uranium enrichment has taken place. Although it is unlikely that any substantial uranium mineralization is present at Mount Bower, this occurrence confirms our previous evidence that the Kukri Erosion Surface and the adjacent rocks offer the greatest promise for uranium resources (Zeller and Dreschhoff in press). We believe that the region adjoining the survey area to the south and west should be examined for potential sedimentary uranium concentrations in the basal Beacon Group sediments.

This project is a continuing effort of the University of Kansas and the West German Federal Institute of Geosciences and



Map showing survey area in northern Victoria Land and graphic summary of results. U = uranium; Th = thorium; K = potassium.

Resources. The research was supported in part by National Science Foundation grant DPP 77-21504.

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McMurdo Volcanic Group, northern Victoria Land

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As part of the 1981–82 northern Victoria Land field camp, we examined the Late Cenozoic alkali volcanic rocks of the McMurdo Volcanic Group, from 17 December 1981 to 14 January 1982. Investigations centered mainly on Mount Overlord and vicinity; however, reconnaissance studies also were made in the lower Mariner Glacier area and at the Pleiades (Kyle 1982), Cosmonaut Glacier, Vulcan Hills, and Aviator Glacier. It is apparent that McMurdo Volcanic Group rocks are more extensive than preliminary reconnaissance geologic mapping had indicated (Gair et al. 1969). The area between the lower Mariner Glacier and the Borchgrevink Glacier is probably all volcanic, mainly basaltic hyaloclastites similar to those from the Hallett volcanic province described by Hamilton (1972). The volcanics extend from sea level to the summit of Mount Phillips at the south end of the Malta Plateau, a thickness in excess of 3,000 meters.

Mount Overlord is a 3,396-meter-high stratovolcano composed predominantly of differentiated alkali rocks ranging from trachyandesite to trachyte. Younger basaltic cones containing ultramafic inclusions occur around the base of the volcano. Mount Overlord has a 1-kilometer-wide caldera and a very youthful appearance. Surprisingly, three potassium-argon (K-Ar) age measurements give a mean date of about 7 million years (Armstrong 1978). Exposures in the caldera walls show that the upper part of the volcano is composed of alternating trachyandesite and trachyte flows and associated pyroclastic rocks. One of the final eruptions carried a large number of plutonic xenoliths to the surface. Some of these are derived from the local granitic basement; however, the great majority are believed to be cognate and to consist predominantly of essexites, syenites, and nepheline syenites. A detailed study of the petrology and geochemistry of Mount Overlord is in progress.

Parasite Cone, about 8 kilometers northwest of Mount Overlord, is composed of hyaloclastite which apparently formed during a subglacial eruption prior to the downcutting of the Astronaut Glacier and Aviator Glacier valleys. Radiometric dating of Parasite Cone may aid in defining former ice levels in the area, especially for the Evans Névé, and may provide a maximum age for downcutting of the Aviator Glacier drainage. Hyaloclastites are also common along Aviator Glacier, particularly northwest of Eldridge Bluff and Co-pilot Glacier. Unfortunately, most of these hyaloclastites are inaccessible for sampling.

A very young, small, basaltic vent is located on the south side of the Cosmonaut Glacier, about 2 kilometers upstream from Aviator Glacier. During a period of higher ice level, lava flows poured down a steep granite wall into Cosmonaut Glacier, creating a chaotic deposit of intermixed till, hyaloclastite, and basalt. The deposit caused a slight diversion in the flow of the glacier.

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Field studies of the Wilson and Rennick Groups, Rennick Glacier area, northern Victoria Land

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The Wilson and Rennick Groups are metamorphosed sedimentary and volcanic rocks generally believed to be the oldest metamorphic units exposed in northern Victoria Land (Dow and Neall 1974; Gair 1967; Laird, Bradshaw, and Wodzicki 1982; Wodzicki, Bradshaw, and Laird 1982). The main purpose of our project is to determine whether these groups represent more highly metamorphosed equivalents of either the Robertson Bay Group or the Bowers Supergroup (e.g., Tessensohn et al. 1981), or whether they represent a crystalline basement complex.

We selected the following four areas for field studies: (1) three spurs of Mount Bernstein (71°37′S 163°07′E) in the Lanterman Range—northeast, east toward Reilly Ridge (71°32′S 163°18′E), and west toward the junction of the Orr and Rennick Glaciers; (2) Salamander Range near Mount Pedersen (72°05′S 164°02′E); (3) Sequence Hills (73°03′S 161°15′E); and (4) Helliwell Hills near Mount Remington (71°46′S 161°17′E). Our fieldwork was done largely on foot from six helicopter-supported satellite field camps during the period 6 November to 28 December 1981. In addition, we made day trips by helicopter to the east spur of Mount Bernstein, to the northern Salamander Range, and to Mount Weihaupt (72°37′S 161°03′E) and a snowmobile trip to the southern Salamander Range.

The Wilson Group of the Lanterman and Salamander Ranges appears to belong to a single structural-metamorphic unit. In the Lanterman Range we recognized the following stratigraphic units (from east to west)—(1) conglomerate, in part polymict, with clasts of quartzite, marble (rare) felsic rocks, plutonic rocks, and chloritic and amphibolitic schists; (2) mica and biotite-amphibole schists containing layers and pods of amphibolite and ultramafic rocks; (3) biotite-quartz schist commonly with centimeter-sized pods of amphibolitic granulite; and (4) mica schist, amphibolite, quartzofeldspathic gneiss, and subordinate calc-silicate granulite. The conglomerate, which is folded into a syncline plunging shallowly to the north-northwest, has an outcrop width of 2 kilometers on the east spur of Mount Bernstein and is exposed on the northeast spur (compare Wodzicki, Bradshaw, and Laird 1982, figure 68.1). The rocks we examined in the Salamander Range resemble our units 3 and 4 in the Lanterman Range except that the calc-silicate granulites (some containing grossular) are more spectacular. Contacts between the four units are conformable and to some extent gradational.

Pegmatite veins are abundant around Mount Bernstein in the Lanterman Range and in the Salamander Range, while veins of more mafic rocks were found only in the Salamander Range. The Granite Harbor Intrusive near the Orr Glacier (see Tessensohn et al. 1981, plate 1) is a heterogeneous plutonic complex of hornblendic and biotitic rocks.

In the Lanterman Range, metamorphic grade increases gradually from east to west, reaching sillimanite grade east of Mount Bernstein; rocks in the Salamander Range are all sillimanite grade. The structure is dominated by a subvertical schistosity trending north-northwest and forming the axial planes of the earliest recognizable folds. It has subsequently been folded twice. The youngest generation of folds may be related to the faults bounding the Lanterman Range, while the earliest structural episode overlapped pegmatite emplacement.

The Rennick Group in the Sequence Hills consists of quartzites, mica schists, calc-silicate granulite, and marble. Distinctive spotted mica schists contain cordierite porphyroblasts and, in places, fine garnet euhedra. Andalusite prisms several centimeters long are associated with quartz pods similar to those from the Daniels Range (Kleinschmidt 1981, figure 10). Tourmaline-bearing pegmatites are abundant; a few contain andalusite and fibrolite. Two generations of folds are recognized in the metasediments. The pegmatites apparently were emplaced late in the development of the younger folds. The youngest structures are reverse faults dipping 30° to 40° to the east.

The Helliwell Hills Wilson Group is largely phyllite or quartzose biotite and mica schists. Plutonic rocks include mafic and leucocratic varieties, as well as tourmaline pegmatites; several episodes of intrusion are indicated. Metamorphic grade rises dramatically (over a cross-strike distance of about 4.5 kilometers) from very-fine-grained phyllite in the east to fibrolite-bearing migmatite in the west. Andalusite-bearing quartz segregations occur locally with spotted (cordierite) schists. The structure is dominated by a subvertical foliation which parallels transposed compositional layering. This foliation is locally folded. However, all structures appear to be related to a single episode of progressive inhomogeneous deformation spanning emplacement of the plutonic rocks.

Our fieldwork confirms the distinction noted by others between the Wilson Group east of the Rennick Glacier and the Wilson and Rennick Groups west of it. Amphibolites and conglomerate apparently are not found west of the Rennick Glacier, whereas tourmaline pegmatites, spotted schists, and andalusite-bearing quartz pods are characteristic of the western areas.

In our traverse east of Mount Bernstein, we did not find a structural or metamorphic break between Wodzicki, Bradshaw, and Laird's (1982) Husky Conglomerate and Wilson Group conglomerate. The two conglomerates appear to form part of the same stratigraphic sequence and show the same deformation history. Our field data suggest that the Wilson Group conglomerate is part of the unit mapped as Husky Conglomerate. If the Husky Conglomerate can be correlated with a part of the Sledgers Group (Laird, Bradshaw, and Wodzicki 1982, suggest correlation with either the Sledgers Group or the Robertson Bay Group), then the Wilson Group in the Lanterman and Salamander Ranges is most likely a more highly metamorphosed equivalent of portions of the Bowers Supergroup, as suggested by Tessensohn and others (1981). In any case, we found no evidence for the Wilson and Rennick Groups being rejuvenated crystalline complexes of the east antarctic Precambrian shield.

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Paleomagnetic investigations of the Sledgers Group, Bowers Mountains, northern Victoria Land

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Structural mapping and sampling of the Sledgers Group for paleomagnetic analysis was conducted during the 1981–82 field season in the Lanterman and Explorers Ranges of the Bowers Mountains, northern Victoria Land. Approximately 400 paleomagnetic drill cores were taken at 44 volcanic and sedimentary drill sites in the vicinity of the Alt and Carryer Glaciers, tributaries of the lower Rennick Glacier, and 113 oriented hand samples were taken at 12 volcanic sites. Of these 56 sites, 42 are from subaerial and submarine flows of the Vendian to Lower Cambrian (Adams et al. 1982) Glasgow Volcanics, which attain their greatest thickness between the Alt and Carryer Glaciers. These predominantly basaltic to andesitic volcanics contain minor younger rhyolitic subaerial flows and breccias and epizonal plutons. The remaining 14 sites are from breccias and conglomerates of the Glasgow Volcanics and consanguinous sediments of the Molar Formation, and from mudstones, dikes, and sills of overlying Carryer Conglomerate (Laird, Bradshaw, and Wodzicki 1976). Figure 1 gives locations of these 56 sites.

Drill sites were located to either side of the northwest-trending fold axes of major folds in the Sledgers Group (figure 1), allowing application of the fold test (Graham 1949; McElhinny 1964) to assist in the isolation and identification of primary magnetization and later components. Breccia and conglomerate clasts of the Glasgow and Molar Formations were sampled for application of the conglomerate test (Graham 1949; Starkey and Palmer 1970) to evaluate magnetic stability.

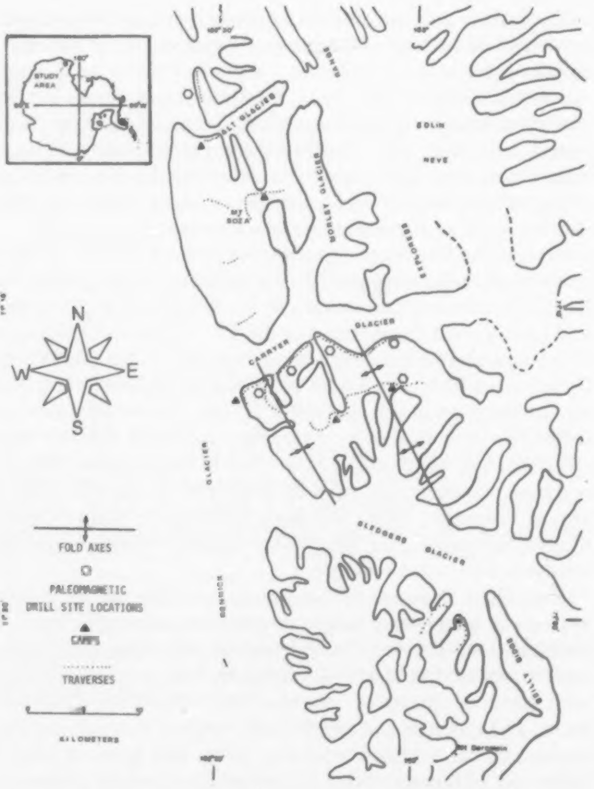

Figure 1. Map of primary field area.

In addition to constraining various pre-Cretaceous reconstructions of Australia and Antarctica, determination of the precise apparent polar wandering path from northern Victoria Land will provide information bearing on other salient tectonic issues, including the relative motion between East and West Antarctica during the Tertiary proposed by Cox and Gordon (1978). Paleomagnetic analysis of all samples is under way.

Paleomagnetic samples also were obtained from plutonic rocks of the Admiralty and Granite Harbor Intrusives; a total of 103 drill cores were taken at six sites in the Salamander and

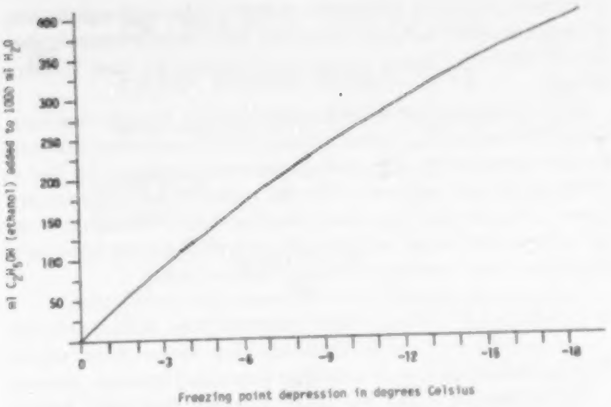

Figure 2. Freezing point depression curve for ethanol/water mixtures.

Alamein Ranges of the Freyberg Mountains, northern Victoria Land. Drilling of the McMurdo Volcanics on Ross Island during equipment checkouts yielded 40 cores from three sites.

Drill cores were obtained using a modified two-stroke, chain-saw-drive unit with a tubular diamond bit. A pressurized plastic pump can with a volume of 6 liters provided drill fluid to the bit, using a specially designed chuck. All drill equipment and fluid was backpacked to the drill sites, since virtually all sites were inaccessible by motor toboggan; good outcrop was confined to areas of high relief. All drill equipment performed flawlessly throughout the season.

Keeping the drill fluid in a liquid state in freezing temperatures was a primary concern. Ethanol was combined with a water/snow mixture to depress the freezing point of the drill fluid. We varied the mixture of ethanol to water according to the ambient temperature. Figure 2 shows a freezing point depression curve for ethanol/water mixtures. When possible, the ethanol was mixed with snow at the drill sites and allowed to melt in the sun overnight, minimizing the total weight of fluid carried into the sites.

The ethanol/water fluid proved to be superior to ethylene glycol mixtures used on previous expeditions (Burmester and Sheriff 1980), for several reasons. Ethanol has a lower density and freezing point, reducing the weight of loads carried in to drill sites, and a lower boiling point, resulting in dry cores instead of the wet, slippery cores obtained using ethylene glycol/water drill fluids. In addition, the ethanol mixture did not cover the driller with slimy fluid.

Water-soluble oil was added to the drill fluid as a bit lubricant, in a 50:1 fluid-to-oil ratio for mafic volcanic and sedimentary rocks, and in a 30:1 ratio for granitic rocks. The addition of water-soluble oil further depressed the freezing point of the drill fluid.

All drill cores were oriented in the field by means of simultaneous sun compass and magnetic compass readings. The orientation data were reduced in the field by means of a programed calculator. The liquid crystal display on our calculator had the advantage of long battery life, with no recharging capability required in the field, but it could not operate in temperatures below freezing and thus had to be kept warm.

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Geology of the Bowers Trough and its possible correlation with the Dundas Trough, Tasmania

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Field mapping of the Bowers Supergroup has been carried out near the Alt, Carryer, and Sledgers Glaciers in the Bowers Mountains (figure 1). The study area lies near the coast facing Australia and thus occupies an important position for pre-Cretaceous plate reconstruction of Gondwanaland. This article compares the geology of the Bowers and Dundas Troughs and discusses their possible correlation.

The geology of the Bowers Mountains was studied in detail during the 1974–75 NZARP (New Zealand Antarctic Research Program) expedition (Adams et al. 1982; Bradshaw, Laird, and Wodzicki 1982; Cooper et al. 1982; Laird, Bradshaw, and

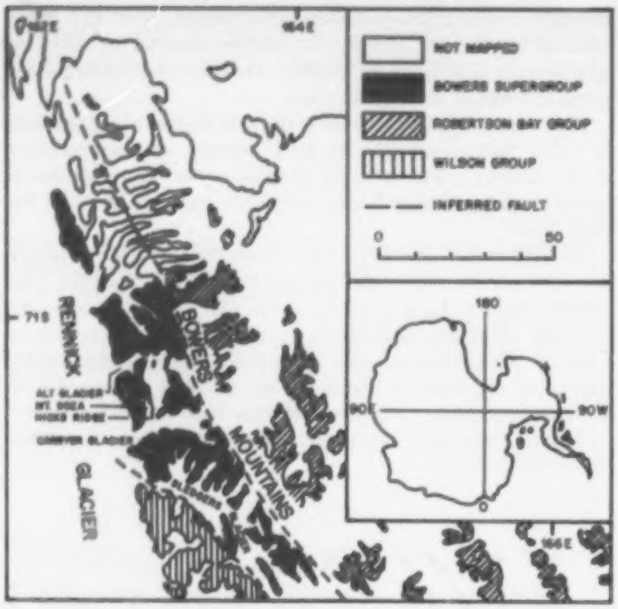

Figure 1. Location of study area.

Wodzicki 1982; Wodzicki, Bradshaw, and Laird 1982). The Bowers Supergroup occupies a northwest-trending structural depression bounded by Precambrian schists and subschists of the Robertson Bay Group and gneisses of the Wilson Group. It has been subdivided into the Sledgers, Mariner, and Leap Year Groups. The Vendian to Early Cambrian Sledgers Group consists of basaltic Glasgow Volcanics and the Molar Formation. The latter consists of shale and well-sorted sandstone interbedded with graded sandstone and chaotic-slide breccia containing felsic volcanic and plutonic debris probably transported from the northeast. The Middle to Late Cambrian Mariner Group consists of mudstone with thin sandstone and limestone beds and rests conformably on Sledgers Group. The Late Cambrian to Ordovician Leap Year Group consists of quartzose sandstone and conglomerate of the Camp Ridge Quartzite in the northeast, and mainly polymictic Carryer Conglomerate in the southwest; both rest unconformably on the Mariner Group. Tessensohn and others (1981), reporting on results of the 1979–80 GANOVEX (German Antarctic Victorialand Expedition) expedition suggest that the Sledgers Group is sedimentologically similar to the Robertson Bay Group and is either a lateral equivalent or is younger.

The geology of the Dundas Trough is summarized by Corbett (1981). Folded Proterozoic schists and quartzites are unconformably overlain by unfossiliferous quartz sandstone, shale, graywacke with mafic volcanic detritus, and mafic lavas of the Success Creek Group and Crimson Creek Formation. In the west this sequence is overlain by the Dundas Group, which is Middle to Late Cambrian (Jago 1979) and consists of lithic volcanic and quartz wacke, conglomerate, siltstone, slate, mafic volcanics, and, toward the east, increasing proportions of felsic volcanic detritus. Eastward it grades into the calc-alkaline felsic volcanics and shallow intrusives (Darwin Granite) of the Mount Read Volcanics, which locally contain massive sulfide deposits (Solomon 1981). The Tyndall Group, consisting of volcaniclastic conglomerates and minor volcanics unconformably overlies Mount Read Volcanics (Solomon 1979) and is mainly Late Cambrian (Jago et al. 1972). The quartzose Owen Conglomerate is Late Cambrian to Ordovician and rests largely unconformably on Tyndall Group, Mount Read Volcanics, and Dundas Group.

The correlation of the Bowers and Dundas Troughs has been suggested by Laird, Cooper, and Jago (1977) on the basis of their similar stratigraphy and geologic history. Grindley and Davey (1982) point out, however, that the Mount Read Volcanics are apparently missing from the antarctic rocks. Furthermore, no correlatives of the Darwin Granite or Tyndall Group have been described from northern Victoria Land to date.

Our work during the 1981–82 season has shown that:

- The Glasgow Volcanics were erupted from volcanic islands and attain their greatest thickness near Mount Soza, where they consist mainly of subaerial flows and breccias. Toward the southeast, along the lower Carryer, they give way to submarine breccias and debris flows, pillow lavas, and minor limestone. Further in this direction, along Sledgers Glacier, the volcanics are progressively interbedded with Molar Formation, which contains minor redeposited volcaniclastic sandstones and breccias.
- A large chaos breccia containing 5-meter angular rhyolite clasts occurs within the upper Glasgow Volcanics along lower Alt Glacier. Slump folds suggest transport from the east.
- Subvolcanic, premetamorphic granitic plutons intrude Sledgers Group along Hicks Ridge.
- Along the Rennick Glacier, Carryer Conglomerate rests directly on Glasgow Volcanics. It contains clasts of Glasgow and Molar provenance and is intruded by intermediate dikes and sills.

A tentative correlation between the stratigraphy of the Bowers and Dundas Trough, based on present and previous work, is shown in figure 2.

Mount Read Volcanics correlatives have been removed from the Bowers Mountains and are now preserved only as clasts within the submarine slump breccias. Originally they were present to the northeast of the present Bowers Supergroup outcrop, an area now underlain by Robertson Bay Group. The search for massive sulfide deposits in northern Victoria Land is unlikely to be successful unless remanents of Mount Read Volcanics equivalents are preserved in the unmapped northernmost part of the Bowers Mountains.

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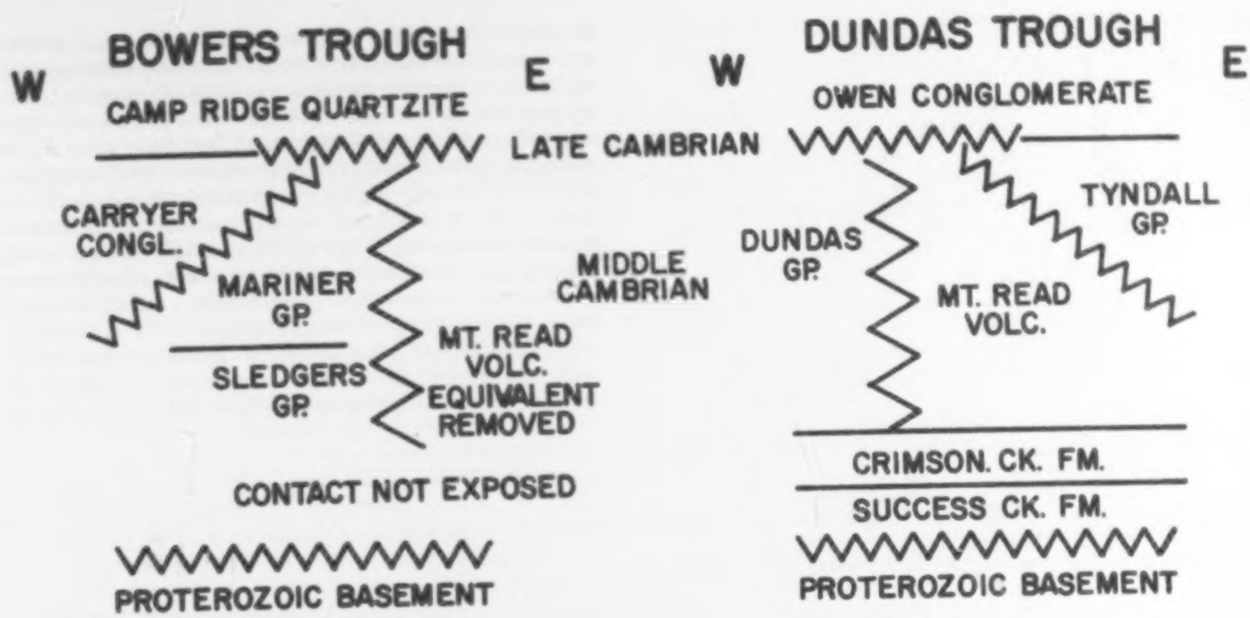

Figure 2. Tentative correlation between Bowers and Dundas Troughs.

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Structural study of the Leap Year Fault, northern Victoria Land

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The Leap Year Fault is a 250-kilometer-long linear feature in the Transantarctic Mountains of northern Victoria Land (figure 1). It separates the Robertson Bay Group on the east from the Bowers Group on the west and also divides areas containing 360-million-year-old Admiralty intrusions from older (470 million years) Granite Harbor granites (Gair et al. 1969; Kreuzer et al. 1981; Tessensohn et al. 1981). The history of movement on this fault, including sense of motion, displacement, and timing, is critical to reconstructing Paleozoic geographies and plate tectonic settings for this part of the ancient Gondwana continental margin (Craddock 1972; Elliot 1975).

During the last part of December 1981 and the first half of January 1982, I visited 15 localities near the trace of the fault, from McKenzie Nunatak in the north to the Mount McCarthy-Mount Burton area just east of the head of the Mariner Glacier. Operating out of the northern Victoria Land base camp on the Evans Névé, I used field camps and close-support helicopter traverses to examine the sites. Assisting in the field was Ellen K. Wright.

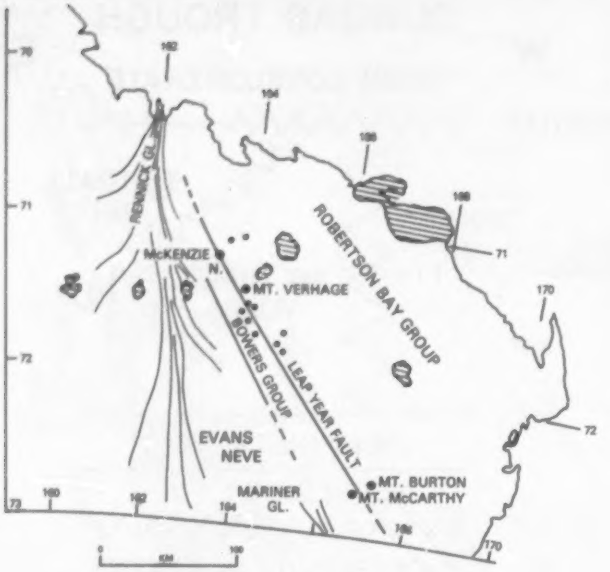
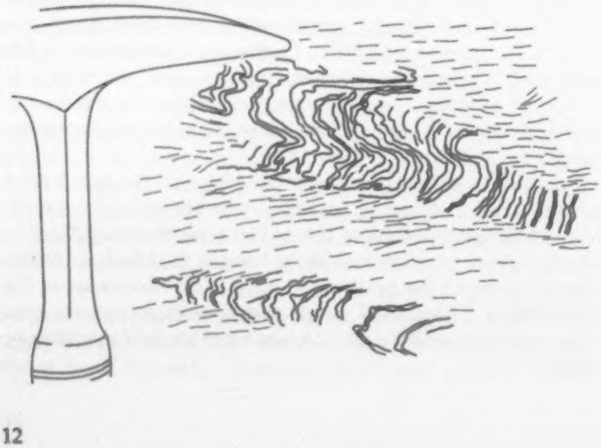


Figure 1. Index map showing location of the Leap Year Fault in northern Victoria Land. Dots indicate localities studied.

The fault itself was mostly under ice (this was expected, since fault zones normally are more easily eroded than are unfractured rocks at a distance from fault zones). Consequently, the strategy was to observe such secondary features as minor folds, faults, striations on fault planes, and kink bands on exposures as near the fault as possible and to use this information as an indication of the major motions on the main fault. The main fault was seen only in the Mount McCarthy-Mount Burton area on a relatively limited exposure.

Results indicate several periods of motion on this important fault. The first, and probably the major event in terms of displacement, involved a relatively plastic response, primarily on the Robertson Bay side of the fault, that produced a strongly deformed rock with spectacular mineral banding or segregation from the Robertson Bay shales and graywacke (figure 2). This feature was observed in a strip up to 15 kilometers wide paralleling the fault trace, although there are a few areas much nearer the fault that do not show this feature. The 15-kilometer-wide strip probably indicates the schistosity and mineral lamination discussed by Bradshaw, Laird, and Wodzicki (1977) and possibly that of Crowder (1968). This banding appears to be an accentuation of preexisting cleavage because the orientation parallels cleavage regionally. Gradations from cleavage to this banding were noted, but the banding probably occurred during an additional transposition or overprinting cleavage-forming event. These features are best developed in the finer grained units. Considerable strain analysis on collected oriented-band specimens remains to be done; however, very preliminary indications (early, steep fold axes in quartz bands) are that the motion was largely westward directed, implying thrusting or reverse faulting rather than strike-slip displacement.

Figure 2. Line drawing of transposed bedding and strongly developed mineral banding or schistosity. Hammer point approximately 20 centimeters.



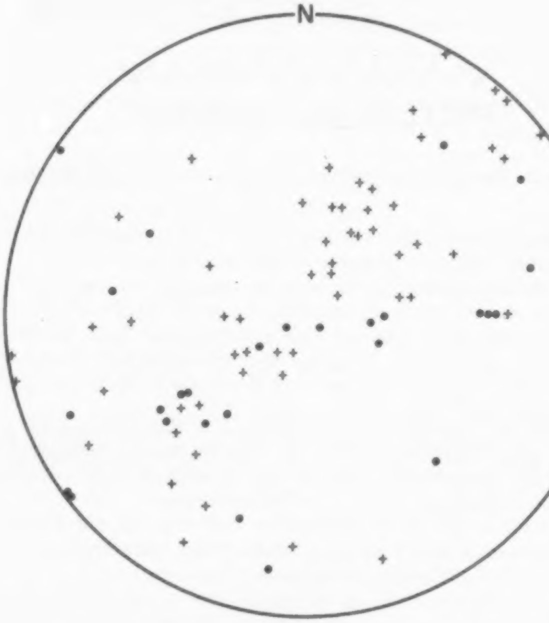


Figure 3. Equal-angle stereoplot of poles to late stage quartz veins (crosses) and striae orientations on slickensided surfaces (dots).

This plastic behavior was not recognized in the quartzites west of the fault except in the Mount McCarthy-Mount Burton area. This may be due to different lithologic response or may reflect original deformation asymmetry. If the motion were primarily thrusting, such asymmetry—with the overriding plate being deformed more than the overridden one—would be expected. Also, the extraordinarily wide fault-related deformation zone may be a result of a low-angle fault plane dipping eastward under the Robertson Bay Group rocks.

Superimposed on this early deformation are at least three generations of brittle faulting. Sequences of faulting were worked out for individual areas by crosscutting relationships; however, correlations between local sequences have not been resolved. Both compressional features (thrusts and kink bands) and extensional features (quartz veins with growth fibers) were present. Orientations of abundant striations on fault surfaces (slickensides) and other features clearly indicate normal or reverse faulting with little or no strike-slip movement (figure 3). The last of these appears related to intrusion of diabase. Several small dikes and sills of diabase were seen on McKenzie Nunatak and on the ridge 8 kilometers south of the summit of Mount Verhage and are known from other places along the fault (Laird personal communication). Should these date as Farrar equivalents, as seems likely on the basis of lithologic similarity and lack of deformation, the age of these brittle deformations would be restricted to the pre-Jurassic.

To place further constraints on the faulting history, oriented samples will be slabbed and thin sections made for fabric analysis, especially to resolve the early plastic deformation style. Fluid inclusions in the brittle deformations will be studied in an attempt to improve correlation of brittle events, and argon-40/argon-39 (^{40}Ar/^{39}Ar) incremental release spectra will be obtained in an attempt to date both the early faulting and possibly the late kinking events.

These preliminary conclusions about the Leap Year Fault kinematics and other regional relations imply that the Robertson Bay Group may have originated well to the east of its present position and arrived by thrusting during the end of the Ross Orogeny, or possibly as late as the late Devonian Admiralty intrusive event. Therefore, in addition to the better known late high-angle faults that produced the large structural blocks in northern Victoria Land, large-scale thrust faulting may play an important part in the tectonic history, especially during the Paleozoic.

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Beacon fossils from northern Victoria Land

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An extensive search for fossils in the Beacon Supergroup of northern Victoria Land during the 1981–82 field season yielded no vertebrates; however, numerous plant and trace fossil localities were discovered. Our season ran from 30 November 1981 to 15 January 1982, and all our field studies were in conjunction with J. W. Collinson's group, which included Collinson and Barry Roberts of Ohio State University and N. R. Kemp of the Tasmanian Museum and Art Gallery (Hobart, Australia).

The Beacon explored in the Freyberg Mountains included exposures at Smiths Bench (72°10′S 163°8′E), Mount Baldwin (72°15′S 163°15′E), Monte Cassino (72°21′S 163°40′E), a series of unnamed ridges along the western side of Moawhango Névé (72°17′S 163°30′E), the eastern edge of Mount Massell (72°30′S 163°28′E), and an unnamed peak at the northernmost end of the Alamein Range (72°2′S 163°16′E). Localities south of Neall Massif in the Salamander Range (72°9′S 164°30′E), at Boggs Valley (71°56′S 161°30′E) in the Helliwell Hills and at DeGoes Cliff (71°45′S 162°00′E), and at the head of the Jupiter Amphitheatre (71°35′S 161°53′E) in the Morozumi Range also were searched. Farther south, Roberts Butte (72°39′S 160°07′E), the Lichen Hills (73°20′S 162°07′E), the Vantage Hills (73°32′S 162°28′E), and the western flank of Gair Mesa (73°31′S 162°45′E) received attention. These areas contain nearly all of the mapped Beacon north of 73°37′S in the Transantarctic Mountains (Gair et al. 1969).

Although none of the northern Victoria Land Beacon sections mentioned contained vertebrates, nearly all of them contained fossils of some type, usually unidentifiable, poorly preserved wood impressions in sandstone. Boggs Valley in the Helliwell Hills and DeGoes Cliff in the Morozumi Range yielded well-preserved, carbonized leaf and stem impressions. So far identified are both *Glossopteris* sp. and *Gangamopteris* sp. (figure 1). As yet unidentified reproductive structures also were discovered, including a seed from ?*Glossopteris* sp. and a fertiliger capitula of ?*Glossopteris stricta*. Specimens of *Vertebraria*, which apparently represent glossopterid-gangamopterid roots (Schopf 1976), occur in association with the leaves. Exposures at Monte Cassino produced scrappy remains of *Glossopteris* sp. At all three localities, the fossils were obtained from black shales. Inter-

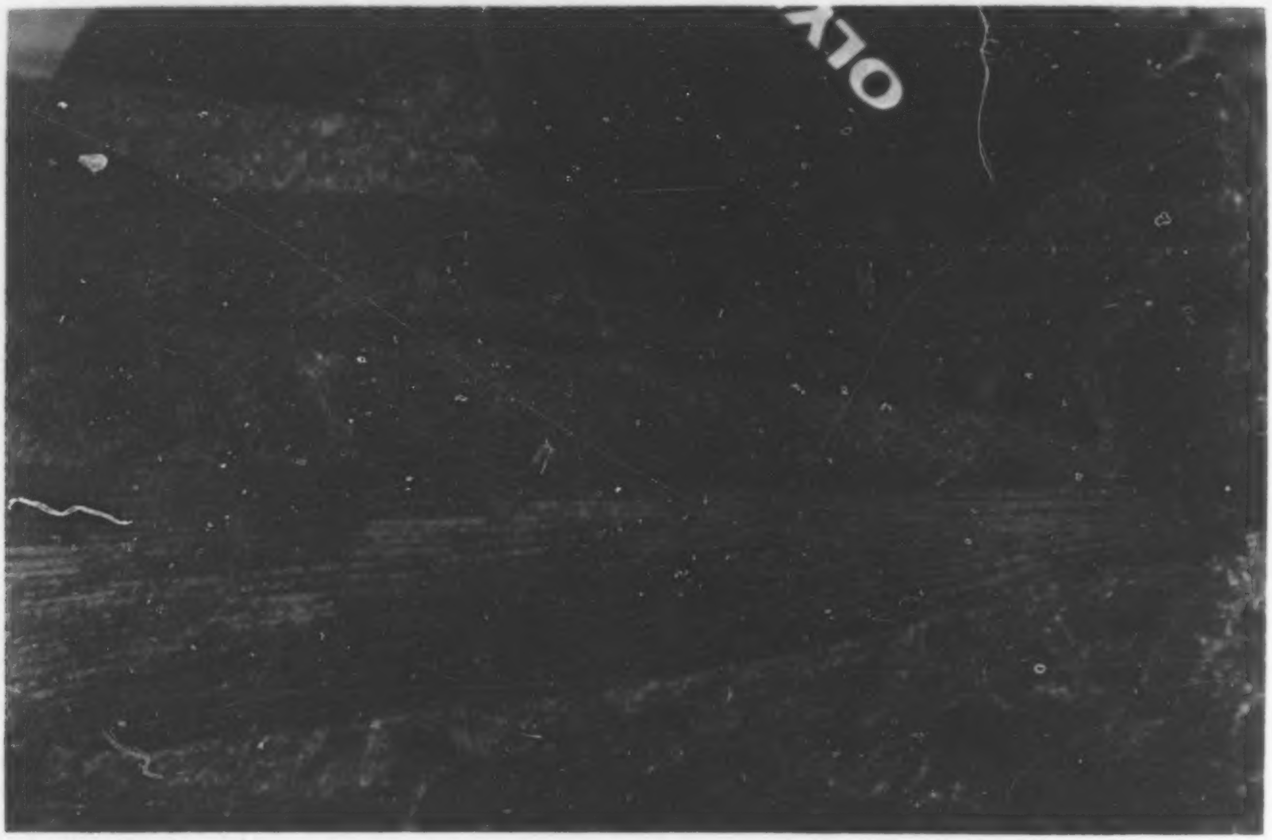

Figure 1. *Glossopteris* sp. (top) and *Gangamopteris* sp. from DeGoes Cliff in the Morozumi Range. ?Glossopteris sp. seed is in the middle-right portion of the picture.

estingly, the Beacon of these areas is mapped as Triassic (Gair et al. 1969), yet the *Gangamopteris-Glossopteris* flora indicates an early Permian age. Samples collected by J. W. Collinson at numerous localities, including those listed earlier, will be analyzed for Triassic pollens. The Beacon of northern Victoria Land yielded no positive Triassic megafossils of any type.

Sandy Beacon exposures on the western side of the Moawhango Névé showed extensive burrowing (figure 2). Numerous vertical burrows and several types of horizontal traces were found. The vertical burrows closely resemble similar structures reported from lower Beacon rocks (Vialov 1962; Webb 1963; Webby 1968) that have been attributed to marine worms. Numerous insect taxa also construct identical burrows (Ratcliffe and Fagerstrom 1980). Some of the vertical burrows that are filled with sand and lack distinct walls could be interpreted as shelter burrows of insects. However, since insect burrows generally lack an internal lining (Ratcliffe and Fagerstrom 1980), the traces that possess alteration halos and tunnel linings probably were formed by annelids that lined their burrows with mucus and/or sediment.

At the Smiths Bench locality a lateral root system is preserved in mud-cracked flood deposits. Shallow vertical roots exhibit radiating secondary rhizomes. The study of these invertebrate and plant trace fossils in conjunction with J. W. Collinson's sedimentological work will allow accurate environmental interpretations of the Beacon of northern Victoria Land.

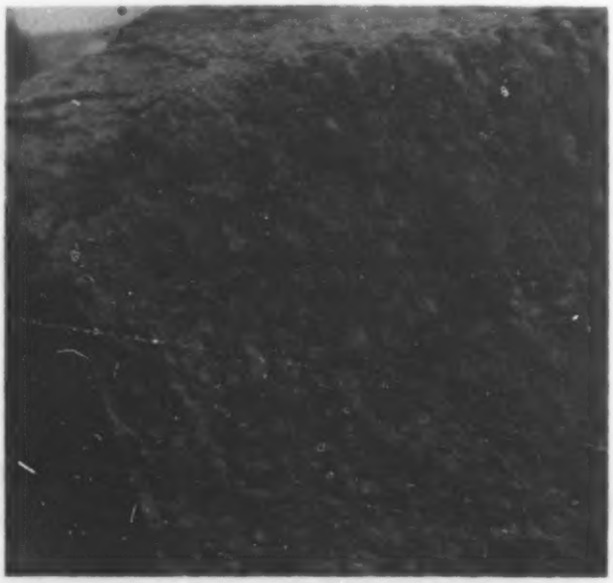

Figure 2. Burrowed surface of the Beacon at exposure west of the Moawhango Névé.

Mount Feather (77°58'S 160°20'E) and the Allan Hills (76°40'S 159°45'E) of southern Victoria Land were visited near the end of the season. These exposures also lacked vertebrates; however, previously documented *Glossopteris* and *Dicroidium* floras were discovered in the Allan Hills.

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Sedimentology of the Takrouna Formation, a Permian-Triassic fluvial deposit in northern Victoria Land

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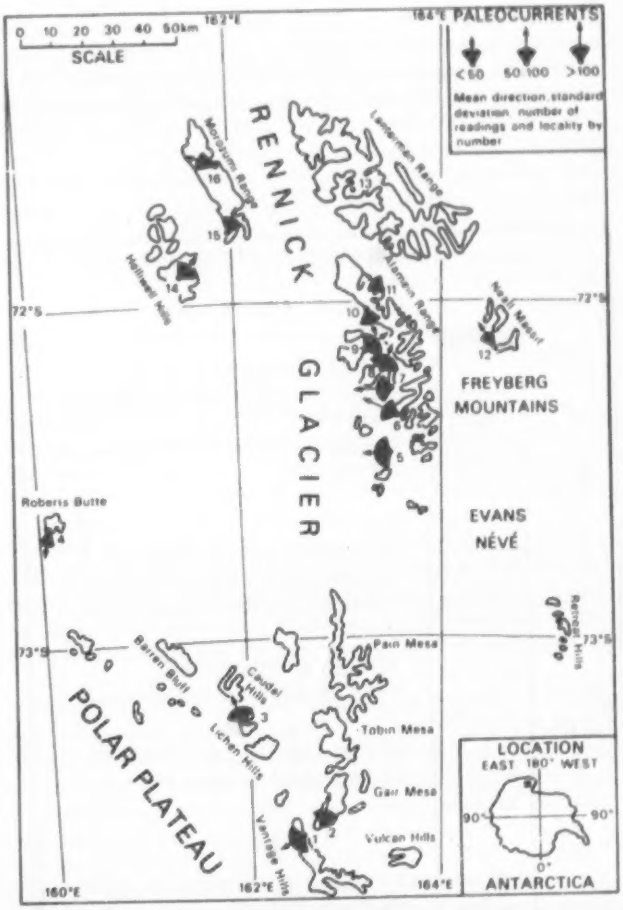
Sedimentologic studies of Permian-Triassic fluvial rocks in northern Victoria Land were conducted from 30 November 1981 to 3 January 1982 by a three-man field party including the authors and Barry L. Roberts, an undergraduate geology student at Ohio State University. Localities in the Freyberg Mountains (figure 1) were reached by motor toboggan from the northern Victoria Land camp; more distant localities were visited by helicopter. Eleven stratigraphic sections were measured at eight localities (1, 3–10, 16), and two other localities (14 and 15) were visited. Observed by helicopter were outcrops at Takrouna Bluff (71°59'S 163°22'E; 11), Lanterman Range (13), Gair Mesa (2), Vulcan Hills, and along the margin of the polar plateau from Roberts Butte to the southern end of the Vantage Hills.

The Takrouna Formation is lithologically similar over its regional extent, consisting of up to 300 meters of crossbedded feldspathic to quartzose sandstone interbedded with carbonaceous or noncarbonaceous silty mudstone and minor coal. In the Freyberg Mountains the lower 200 meters of section are more carbonaceous than the rocks above. The formation is finer grained and more carbonaceous in the Morozumi Range and the Helliwell Hills than it is in the Freyberg Mountains. The sequence at Neall Massif contains coarse feldspathic sandstone and granitic conglomerate, indicating a proximal source. This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GLACIER
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Lanterman Range
Helliwell Hills
Alamein Range
Neall Massif
FREYBERG MOUNTAINS
EVANS NÉVÉ
72°S
Roberts Butte
Retreat Hills
73°S
Barren Bluff
Caudal Hills
Lichen Hills
POLAR PLATEAU
Pain Mesa
Tobin Mesa
Gair Mesa
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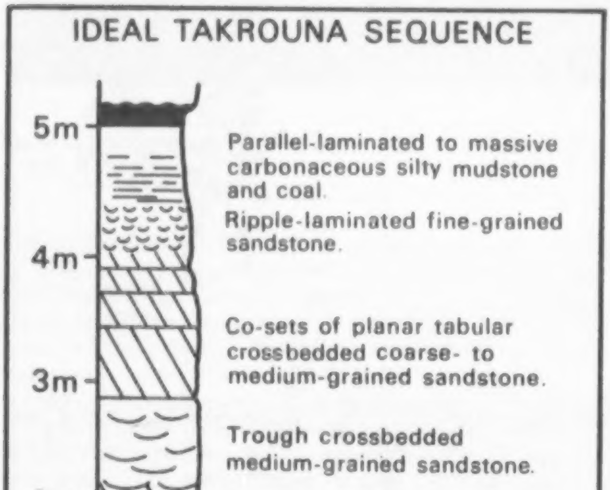
Figure 1. Map of northern Victoria Land showing localities and paleocurrent data. Localities are: (1) Vantage Hills, (2) Gair Mesa, (3) Section Peak, (4) Roberts Butte, (5) small ridge east of Mount Massell, (6) Monte Cassino, (7) ridge within Moawhango Névé, (8) Mount Baldwin, (9) Smiths Bench, (10) Alamein Range, (11) Takrouna Bluff, (12) ridge south of Neall Massif, (13) Lanterman Range, (14) Boggs Valley, (15) DeGoes Cliff, and (16) head of Jupiter Amphitheatre. Paleocurrent data at localities 2, 11, and 14–16 are from B. Walker (personal communication, 1982).

locality is near the eastern limit of Permian-Triassic exposures in northern Victoria Land, which we interpret as the margin of the depositional basin. The westernmost exposures along the margin of the polar plateau are relatively thin and consist of coarse feldspathic sandstone, indicating a position near the western margin of the basin. Coals are best developed along the axis of the basin in the Morozumi Range and the Helliwell Hills. Regionally, the Takrouna Formation overlies a rugged, locally deeply weathered surface of granitic and metamorphic basement rocks. At the south end of Gair Mesa (locality 2) it is unconformably overlain by Kirkpatrick Basalt (Jurassic).

An ideal sedimentary sequence for the Takrouna Formation in the Freyberg Mountains is shown in figure 2. This sequence is seldom fully developed in one cycle. Sections are dominated by coarse- to medium-grained, trough crossbedded, channel-form sandstone. Cycles range from less than 1 to 10 meters in thickness. The larger basal channel surfaces exhibit local relief on the order of 0.5 to 1.5 meters. Pebbles of quartz and basement rock and intraformational clasts are concentrated along channel bases and along scour surfaces.

Trough crossbedding occurs in sets 0.3 to 1 meter thick; the larger sets generally occur near the base of cycles. Planar tabular crossbedding is most common in coarse-grained sandstone and therefore is more abundant in sections near the basin margins such as Neall Massif and Vantage Hills. Orientation of planar sets diverge from trough crossbed directions at these localities by an average of 75° and 95°, respectively. Planar sets are generally 0.3 to 2 meters thick, but may be as thick as 5 meters. These occur as solitary sets or as cosets of decreasing thickness upward. At a locality near Moawhango Névé (locality 7), closely crowded vertical-tube burrows approximately 1 centimeter in diameter penetrate as deep as 2 meters through a sequence of planar tabular crossbed sets that at the tops have been modified by trough crossbedding or ripple cross-lamination.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Parallel-laminated to massive carbonaceous silty mudstone and coal.
Ripple-laminated fine-grained sandstone.
Co-sets of planar tabular crossbedded coarse- to medium-grained sandstone.
Trough crossbedded medium-grained sandstone.
Planar tabular crossbedded coarse-grained sandstone.
Trough crossbedded coarse- to medium-grained sandstone; mud drapes on some scours.
Scour surface overlain by conglomerate.

Figure 2. Composite section of ideal Takrouna sequence, which closely resembles the Battery Point sequence of Cant (1978).

Parallel-laminated, fine-grained sandstone, in some cases with parting lineation, and silty carbonaceous or greenish-gray mudstone occur at the top of the more complete cycles. Silty mudstone also occurs as thin drapes on scour surfaces or as lenticular channel fills. Rarely, coals occur at the top of cycles. Coalified wood in the form of coaly streaks occurs along scour surfaces. Thicker carbonaceous units represent channel-fills. For example, a channel-fill at Monte Cassino (locality 6) is 7 meters thick in the center and approximately 100 meters across. It is composed of carbonaceous shale interbedded with 10-centimeter-thick beds of ripple-laminated, fine-grained carbonaceous sandstone. Coalified calamitid stems and *Glossopteris* leaves occur on parting surfaces. These types of channel-fills are more common in the finer-grained facies in the Morozumi Range and the Helliwell Hills in the central area of the basin.

The ideal sedimentary sequence for the Takrouna Formation (figure 2) closely resembles the Battery Point sequence in the Devonian of Quebec (Cant 1978; Cant and Walker 1976), which is a facies model for deposition by sandy braided streams. In this facies model, large-scale trough crossbedded sandstone represents in-channel deposition by migrating dunes. Large planar tabular crossbeds are formed in the channel by the progradation of transverse bars. Small-scale planar tabular crossbeds, ripple-laminated and parallel-laminated sandstone, and mudstone developed on bar tops by vertical accretion.

The distribution of facies, the composition and grain size of sediments, and the paleocurrent data suggest that the Takrouna Formation was deposited by a system of sandy braided streams in an elongate northwest-trending basin that developed during the latest Carboniferous. This basin approximately conformed to the complex graben feature now occupied by the Rennick Glacier. Probable source terrains were the extensive basement rocks now exposed at the northeast corner of northern Victoria Land and on the east antarctic craton.

Paleocurrent directions at various localities (figure 1) generally indicate dispersal in northerly to westerly directions along the axis of the theorized basin. Large numbers of trough crossbed measurements sampled through relatively thick sequences remain consistent at each locality (e.g., Monte Cassino, locality 6, $\bar{x} = 295^\circ$, $s.d. = 44^\circ$, $n = 164$; Neall Massif, locality 12, $\bar{x} = 326^\circ$, $s.d. = 26^\circ$, $n = 77$), suggesting that major drainage patterns were stable through time and that aggradation was rapid.

The trend of the northern Victoria Land basin and the thinning of sediments toward the south along the margin of the polar plateau suggest that coeval sequences in southern and northern Victoria Land occupied separate structural and depositional basins. Although postglacial sequences in both areas contain coal measures, those in southern Victoria Land were deposited by meandering rather than braided streams (Barrett and Kohn 1975). The Takrouna Formation is similar to the lower part of the Feather Sandstone (Upper Permian) that overlies the coal measures in southern Victoria Land. Sediments in the Triassic of southern Victoria Land, the central Transantarctic Mountains, and northern Victoria Land are in part volcaniclastic.

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Geological investigations of early to middle Paleozoic magmatic rocks, northern Victoria Land

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During the 1981–82 field season we collected lower to middle Paleozoic plutonic rocks throughout northern Victoria Land and mapped and collected Devonian volcanic rocks at Gallipoli Heights. Two groups of granitoid intrusions have been identified in northern Victoria Land on the basis of geographical distribution and sparse isotopic age data. The older Granite Harbour Intrusives, associated with the Ross Orogeny, crop out in the western portion of the area and have ages between of 400 and 500 million years. The younger Admiralty Intrusives crop out in eastern areas and have ages of between 300 and 385 million years. We will undertake laboratory analyses of these rocks for major-element, trace-element, and strontium-isotope geochemistry to determine more accurately the age distribution of the granitoids and whether or not subdivision on geochemical grounds is warranted. A recent model of granitoid genesis which categorizes such rocks by source terrane according to various petrological and geochemical criteria has been formulated on rocks of southeastern Australia (Chappell and White 1974). S-type granitoids are derived from sedimentary terranes, and I-type from igneous terranes. Because southeast Australia was adjacent to northern Victoria Land at the time of granitoid genesis prior to continental breakup, this is an excellent area for testing the model. In Australia there is a boundary between S- and I-type granitoids. Extension of this line into Antarctica will furnish a geological constraint on reconstructions between Australia and Antarctica.

During the season we collected samples from each of the major plutons within the operating radius of the helicopters. We also sampled in detail the plutons at the Lichen Hills and the Emlen Peaks; on the Freyberg Adamellite in the Freyberg Mountains (Dow and Neall 1974), and on the Salamander Granodiorite in the southern portion of the Salamander Range (Laird, Andrews, and Kyle 1974). Tent camps were established south of Mount Apolotok in the Salamander Range and south of Monte Cassino in the Freyberg Mountains. Samples from the central and northern Freyberg Mountains were collected by means of a snowmobile working out of base camp.

From field observation of mineralogy, inclusions, and structure, a division of the northern Victoria Land granitoids into S- and I-types seems apparent as a first approximation. The rocks mapped as Admiralty Intrusives have characteristics of I-type granitoids such as sharp, intrusive contacts, homogeneous texture, homogeneous or porphyritic inclusions, and hornblende as a common phase. Most of the rocks mapped as Granite Harbour Intrusives have characteristics of S-type granitoids such as gradational contacts, a varied, often layered texture, numerous schistose inclusions, and a varied mineralogy which at places includes garnet, cordierite, or both muscovite and biotite. Wyborn (1981) reached similar conclusions from work across the northern portion of northern Victoria Land.

While mapping at Gallipoli Heights we discovered that the volcanics unconformably overlie an eroded surface of the Freyberg Adamellite, indicating a period of major uplift and erosion between granitoid intrusions of the Ross Orogeny and Devonian magmatism in this area. Previous workers disagreed about the nature of the contact, but did not observe the critical locality (Dow and Neall 1972, 1974; Sturm and Carryer 1970). The contact and overlying units are now tilted to near vertical, indicating that further deformation occurred after the eruption of the volcanics. Our mapping shows that the volcanic rocks at Gallipoli Heights are a complex of ignimbrites, massive and flow-banded lavas, volcanic breccias, volcaniclastic units, and dike rocks. From field observations it seems that the rocks are not simply rhyolite, as has been suggested, but range perhaps to andesite.

During the early part of the season, our party was accompanied by Andrew J. W. Gleadow, Department of Geology, University of Melbourne, who was collecting granitoid samples for fission-track dating for the purpose of understanding the uplift history of the present Transantarctic Mountains.

We wish to thank the pilots and crews of the helicopters at northern Victoria Land camp for their excellent support. This work was supported by National Science Foundation grant DPP 80-19991.

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Geological investigation of the Daniels Range, USARP Mountains, northern Victoria Land

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During November and December 1981, a party of four (sometimes five) geologists made a circuit of the Daniels Range, northern Victoria Land. Party members were C. J. D. Adams (and substituting for him early in the season, George Grindley) from New Zealand, R. S. Babcock from Western Washington University, Robin Oliver and J. S. Sheraton from Australia, and the author. Our circuit took 44 days. We traveled approximately 700 kilometers by snowmobile and used helicopters for transport to and from the field area, for some reconnaissance, and to move one camp.

The Daniels Range is one of several ranges in the USARP Mountains. It is north-south trending and approximately 80 kilometers long, and it covers an area of about 2,200 square kilometers. Its center is at 160°E 71°30'S. Excellent exposures of bedrock occur along spurs jutting out of the crest of the range and along cliffs on the east and west flanks of the range. By necessity, our investigation was of a reconnaissance nature. However, we did collect samples appropriate to detailed petrologic, geochemical, and geochronological studies.

The northern part of the area, notably at Thompson Spur, is composed of schist and gneiss that have undergone a complex deformational history (see Kleinschmidt and Skinner 1981). These rocks were originally sandstones and shales (and minor limestones) but have undergone regional metamorphism. During metamorphism, some of these rocks were injected by veins of granitic magma. The metamorphic and igneous layers were subsequently intensely folded. More plutonic activity followed.

Most of the rest of the range is of intermixed igneous and metamorphic rocks which we refer to collectively as the Daniels Range Intrusive Complex. Metamorphic rock within the complex is similar to the gneisses and schists found in the Thompson Spur area, except that it occurs as roof pendants, septa within plutons, and, most especially, as very abundant inclusions in granite. Several types of granitic rock occur in the complex.

The most prevalent type of intrusive rock we call "fruitcake," because of the abundance of metamorphic fragments of all sizes. Some of the inclusions are metamorphic rocks with folded granite veins; thus, the "fruitcake" magma postdates the magma injected as veins into the metamorphic rocks. A second type of magma is a layered granite in which adjoining layers contain different amounts of biotite. In places the layered granite and the "fruitcake" granite appear to grade into one another. Elsewhere the layered granite intrudes "fruitcake" or contains large inclusions of "fruitcake." The textures and structures of both types of granite indicate that regional deformation was taking place during and after they were being emplaced.

In places, mafic dikes cut the granites. These are synplutonic dikes that are segmented, stretched, or bent into tight folds. The enclosing granite is not fractured. Clearly, mafic magma intruded cracks in the granite after crystallization was complete, but the granite must have been sufficiently ductile to permit the deformation of the dikes.

It is reasonable to conclude that deformation was taking place while all the rock units were forming. We do not know whether the deformation was a single continuous event or more than one event with intervening times of quiescence. However, all of the previously described rocks are cross-cut by post-tectonic granitic (especially pegmatite) dikes. Probably, equigranular, inclusion-free granite plutons on the west side of the range are genetically related to the post-tectonic dikes.

The post-tectonic granites appear to resemble descriptions of the Ordovician Granite Harbor Intrusives found elsewhere in Victoria Land. It is reasonable to assume that at least the latest granites are time equivalent to Granite Harbor Intrusives. The syntectonic granites in the Daniels Range may be an earlier episode of Granite Harbor Intrusives, with deformation taking place during the Ross Orogeny, or they may, in part, have been products of an earlier orogeny.

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The Kirkpatrick Basalt, Mesa Range, northern Victoria Land

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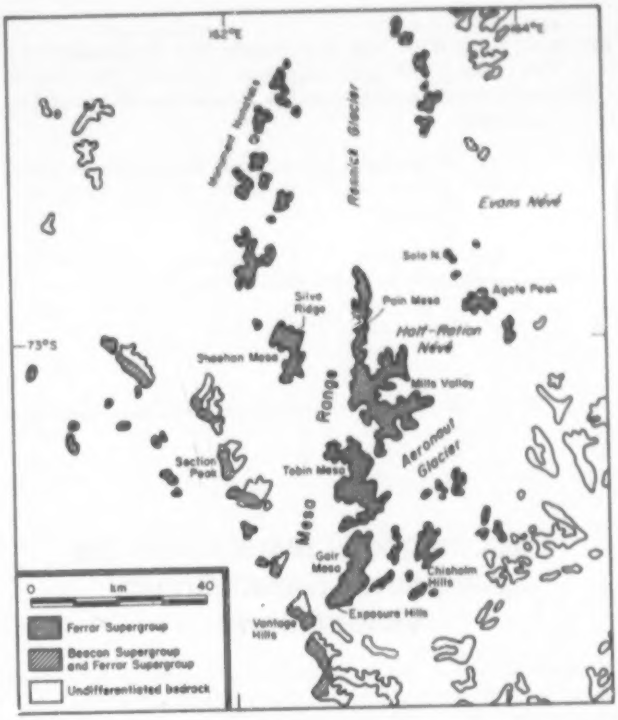
As part of the Northern Victoria Land Project, we examined the Kirkpatrick Basalt of northern Victoria Land between early November 1981 and mid-January 1982. We measured and sampled stratigraphic sections at Solo Nunatak, Pain Mesa (Mills Valley), Tobin Mesa, and Sheehan Mesa (figure). In addition, we examined the Kirkpatrick Basalt at Agate Peak and the Ferrar Dolerite at Section Peak, Vantage Hills, and Exposure Hill (figure).

The base of the basalt sequence is exposed only at the southern end of Gair Mesa, where it rests on Beacon strata that were, subsequent to lava eruption, intruded by diabase sills. No lavas are present west of the Rennick Glacier in the Section Peak to Vantage Hills area, contrary to earlier reports (Gair 1967). At Agate Peak (Nathan and Schulte 1968) the lowest exposed lava, a pillow basalt, is overlain by a thick pyroclastic bed containing blocks of sediment similar to the Mawson Formation that separates rocks of the Beacon Supergroup from the Kirkpatrick Basalt in southern Victoria Land. It is possible that the Agate Peak rocks are close to the base of the Kirkpatrick Basalt. Continuous stratigraphic sections in the Mesa Range are more than 670 meters thick, and the total stratigraphic thickness in the range may well exceed 800 meters. As many as 40 flows are present in several places where sections were measured. If a tentative correlation between Solo Nunatak and the Mills Valley is confirmed by later study, the total thickness will be more than 1,000 meters, and the number of flows more than 50. Flow thicknesses range from less than 1 meter to possibly as much as 100 meters. Sills may be present within the lava sequence, but none have been positively identified. Sedimentary interbeds occur sporadically in the section, but no widespread units have been identified; all sedimentary interbeds found so far *in situ* consist of reworked volcanic material. Lake beds such as occur at Carapace Nunatak (Ball et al. 1979) and in the Beardmore Glacier region (Tasch 1970) have been found only as disrupted blocks of conchostracan-bearing sediment caught up in the pillow basalt at Agate Peak. Fossil wood has been found in a number of places. The presence of a 60-meter (200-foot) sedimentary interbed that was recorded by Gair on Silva Ridge has not been confirmed.

Correlation of flows within the Mesa Range is possible only where flows have distinctive characteristics. Two that appear to be very widespread have been identified; one is a thick black basalt that caps much of the Mesa Range, and the other is a composite flow with a remarkable wavy unit at its top which occurs near the base of Tobin Mesa. Correlation from the Mesa Range to other outcrops is more problematic, but may be aided by information about the chemical and isotopic compositions of the flows. Tentative identification of flows suggests that the Sheehan Mesa section is largely encompassed by that of the Mesa Range. If this is correct, the outcrops west of the Rennick Glacier (Sheehan Mesa to Monument Nunataks) may not be stratigraphically higher than the Mesa Range.



Location map for the Mesa Range region of northern Victoria Land.

Petrographically the lavas are typical tholeiites, having two pyroxenes, plagioclase, and opaques set in a groundmass that ranges from glassy through cryptocrystalline to microcrystalline aggregates of quartzofeldspathic minerals, with or without ferromagnesian minerals (principally pyroxene). Zeolites (stilbite and probably others) and other secondary minerals including quartz (chalcedony) and calcite are a common occurrence, filling vesicles in the upper parts of flows, as well as forming masses within the rubbly flow tops and between the pillows at Agate Peak and elsewhere.

Selected samples collected this season will be analyzed geochemically for major- and trace-element, rare-earth, and strontium-isotopic data. The study of zeolites and other secondary minerals will include identifying mineral and establishing a zonation (if possible) and the relationship to temperature distribution and groundwater circulation in the lava pile.

Major faulting has been postulated for the Rennick Glacier region (Gair 1967; Gair et al. 1969), and it has been suggested that the Kirkpatrick Basalts are situated within a graben, the "Rennick Graben" (Kyle and Cole 1974). There is no compelling evidence for a major fault at the head of the Rennick Glacier between Vantage Hills and Exposure Hill. The lavas have a very low-angle regional dip to the west or northwest, and it is clear that a fault may exist between Sheehan Mesa and Section Peak. Therefore, the postulated fault must have a scissorslike character, opening to the north.

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Paleomagnetic results from the Kirkpatrick Basalt Group, Victoria Land

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Several previous paleomagnetic studies have been made of Jurassic-age antarctic igneous rocks, including (as summarized and referenced in the table): (1) Ferrar Dolerite sills from four localities along the Transantarctic Mountains; (2) Forrestal Gabbros from the Dufek Stratiform Intrusion; (3) Kirkpatrick Basalt lava flows from the Queen Alexandra Range in the central Transantarctic Mountains; and (4) tholeiites from Queen Maude Land. The results have shown generally high stabilities and predominantly normal polarities. The average virtual geomagnetic pole (VGP) is near 55°S 140°W, in good agreement with Jurassic VGP's of Africa, South America, India, and Australia in their Gondwanaland configurations (Schmidt 1976).

The purpose of the present study was to investigate further the paleomagnetism of the Kirkpatrick Basalts. Oriented samples were collected from Kirkpatrick Basalts in the David Glacier Area, southern Victoria Land (55 samples from 25 sites in 24 flows), and at the Mesa Range, northern Victoria Land (60 samples from 15 sites in 15 flows) (figure 1). Paleomagnetic results show that the samples possess strong normal remanence, with stability equal to or greater than that of Ferrar Supergroup dolerites and gabbros. The natural remanent magnetization (NRM) includes a small viscous component that is readily removed by alternating field demagnetization in fields of 20 to 50 millitesla. The mean VGP of the David Glacier samples lies at 55°S 138°W, which is nearly coincident with the average of VGP's previously reported from the Ferrar Supergroup. The mean VGP of the Mesa Range samples, however, lies significantly farther south at 64°S 150°W (figure 2) (page 22).

It is unlikely that the anomalously high latitude of the mean VGP of the Mesa Range samples is an effect of unremoved viscous or chemical components, tectonic tilting or rotation, or incomplete averaging of paleosecular variation. In addition, an

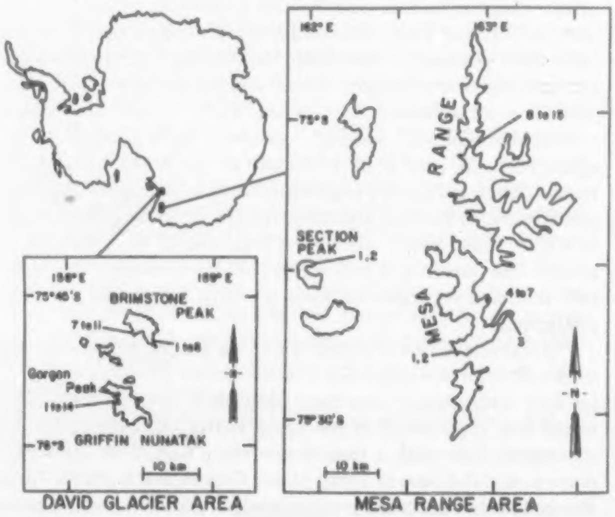

Figure 1. Map showing location of sample sites in the David Glacier area, southern Victoria Land, and at the Mesa Range, northern Victoria Land.

Paleomagnetic results from Ferrar Supergroup igneous rocks[a]

Study	N_1	N_2	AF	Polarity	Remanence				Virtual geomagnetic pole			
					DEC	INC	K	α95	°W	°S	DP	DM
Kirkpatrick Basalts												
Mesa Range (1)[b]	60	15	20	N	266	−80	174	1	150	64	3	3
David Glacier (2)												
Brimstone Peak	29	12	30–50	N	263	−74	156	4	142	56	6	7
Gorgon Peak	26	13	30–50	N	274	−73	122	4	130	56	6	6
Mean	55	25	30–50	N	—[c]	—	141	7	138	55	11	12
Queen Alexandra Range (3)												
Storm Peak	—	12	SEP	N	253	−64	—	7	129	44	9	11
Mount Falls	—	14	SEP	N	225	−71	—	4	137	54	7	8
Mean	—	26	SEP	N	241	−68	—	—	133	49	—	—
Ferrar Dolerite												
Wright and Victoria Valleys (4)	83	46	22.5	N	250	−68	63	3	140	45	4	5
Ferrar Glacier (5)	57	5	NRM	N	255	−76	52	3	142	58	5	5
Queen Alexandra Range (6)	—	7	SEP	N	225	−72	—	5	140	54	8	10
Beardmore Glacier (7)	13	9	15	N	244	−75	18	11	139	59	18	20
Forrestal Gabbro												
Dufek Intrusion (8)	—	—	30	N&R	—	—	—	—	137	60	11	11
Queen Maude Land Tholeiites												
Theron Mountains (9)	8	8	NRM	N&R	64	−68	34	12	136	54	16	16

[a] Abbreviations: N_1 = number of samples; N^2 = number of sites; AF = alternating field demagnetization level, in millitesias; DEC = mean declination, in degrees; INC = mean inclination, in degrees; K = Fisher precision parameter; α95 = semi-angle of the cone of 95 percent confidence; °W and °S denote the position of the estimated paleomagnetic pole; DP and DM = 95 percent probability errors in this estimate, along and at right angles to the paleomeridian, respectively; N = normal; SEP = stable endpoint; NRM = natural remanent magnetization; R = reversed.

[b] Numbers in parentheses indicate sources: (1) this report; (2) this report, Cherry (1981), Cherry and Noltimier (1982); (3) Ostrander (1971); (4) Bull, Irving, and Willis (1962), Bull and Irving (1960); (5) Turnbull (1959); (6) Ostrander (1971); (7) Briden and Oliver (1963); (8) Beck, Burmester, and Sheriff (1979), Burmester and Sheriff (1980); (9) Blundell and Stevenson (1959).

[c] Dashes = not reported.

incremental argon-40/argon-39 (Ar^{40}/Ar^{39}) age obtained from a flow at the base of the Mesa Range is 174.2 ± 1.0 million years (P. R. Kyle and J. F. Sutter unpublished data, New Mexico Institute of Mining and Technology, 1982). This age is indistinguishable from reliable radiometric ages determined for other Ferrar Supergroup rocks (Kyle, Elliot, and Sutter 1981).

The significance of the high-latitude VGP from the Mesa Range samples remains uncertain. It is notable, however, that similar anomalous VGP's have been reported from Tasmanian dolerites (Schmidt and McDougall 1977) that are closely related to the Ferrar Supergroup rocks in age and geochemistry.

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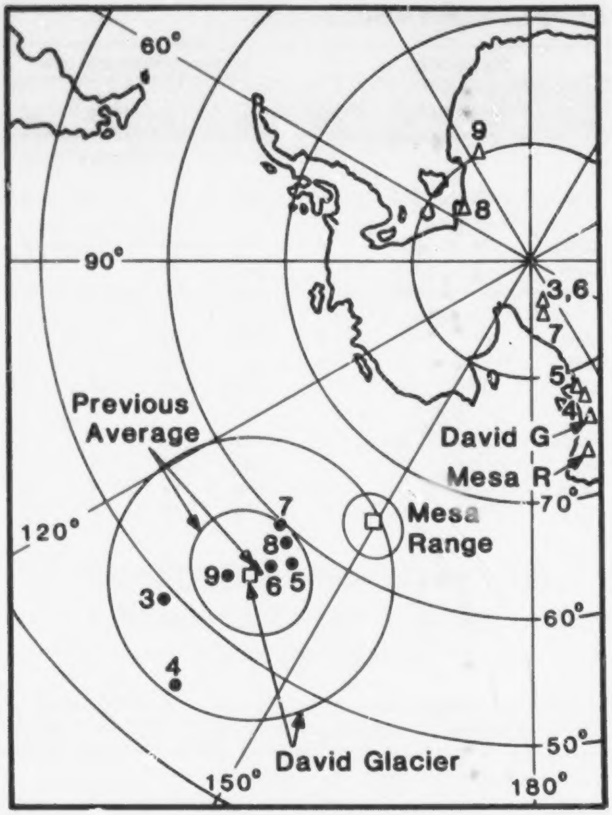

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Figure 2. The mean virtual geomagnetic poles (VGP's) of Ferrar Supergroup rocks from eight localities form an elongate pattern extending from 45°S to 64°S. The mean VGP of David Glacier samples agrees with average VGP of previous studies, but the mean VGP of Mesa Range samples is significantly different. Circles represent results of previous studies; the solid triangle is their average. Squares show the results of this study, and hollow triangles are the study localities. Ellipses of 95 percent confidence are shown for the David Glacier and Mesa Range mean VGP's and for the average of previous studies. VGP's and locations are numbered as in the table.

Petrographic and chemical study of orbicular rocks in western Taylor Valley, southern Victoria Land*

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During the 1980–81 and 1981–82 austral field seasons we mapped and sampled orbicular rocks at several locations in Taylor Valley and at Granite Harbor. We are principally interested in elucidating the mechanism(s) by which orbicular rocks form and in obtaining new information regarding processes of assimilation and chemical transfer in silicate magmas. Taylor Valley is uniquely suited for such a study because orbicules in various stages of development are preserved in outcrop. In an earlier article (Dahl and Palmer 1981), we presented a detailed map showing the geometry of orbicule zones in western Taylor Valley as well as their spatial relationships with Larsen granodiorite and the nearby Skelton Group metasediments. In this article we describe the petrographical, mineral-chemical, and bulk-chemical profiles of a single representative orbicule from the western Taylor Valley area. We then use these profiles to outline the chemical transfer process involved in formation of this orbicule. A polished thin section of this orb (specimen TG81–106D) is shown in figure 1.

The core of this orbicule (figure 1, left) contains the minerals biotite (dark-colored), diopside (intermediate-colored), and plagioclase (light-colored) in equigranular texture. This assemblage is identical to that in some of the gneisses found in place in the nearby Skelton metasediments. Hence, orbicule cores are thought to represent unassimilated metamorphic xenoliths.

The shell structure in orbicular specimen TG81–106D consists of an inner feldspathic region and an outer shell region, the latter dominated by coarse radial hornblende (dark-colored) and plagioclase crystals (figure 1). The inner feldspathic zone contains clusters of intergrown diopside and biotite which occur as "islands" in a "sea" of coarse plagioclase. This part of the shell is thought to represent partially melted xenolith in which the present diopside-biotite clusters persist as unmelted remnants. Quartz and microcline are notably absent in both the orbicule core and shell.

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*Contribution 247, Department of Geology, Kent State University.

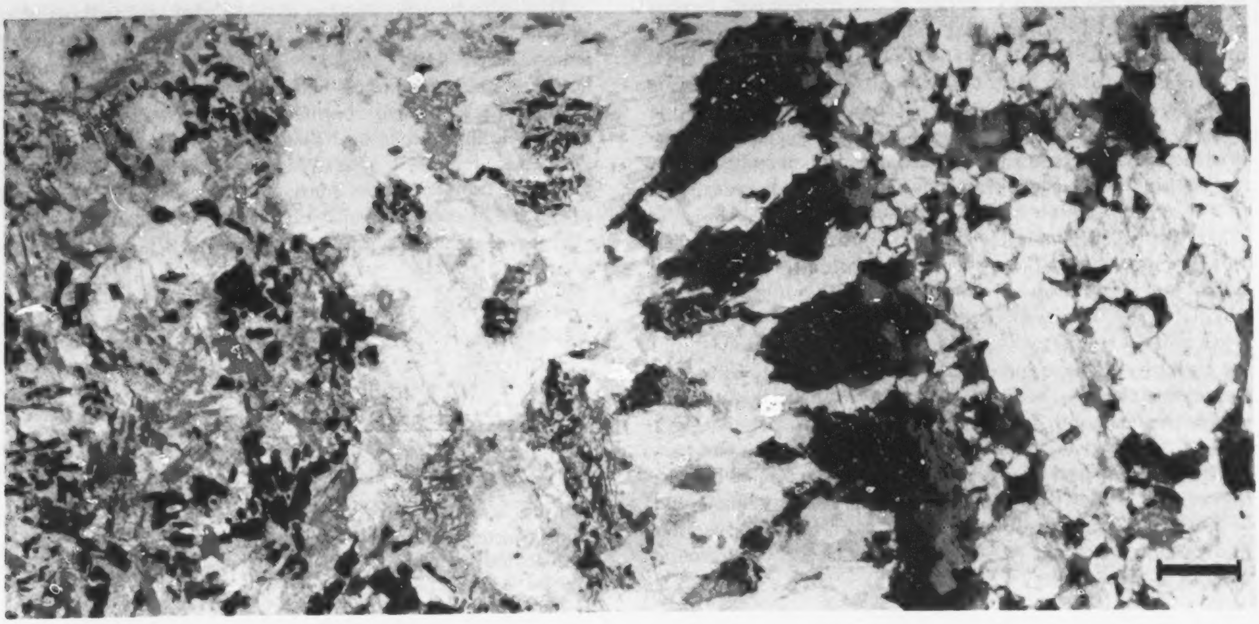

Figure 1. Photograph of part of polished thin section of orbicular specimen TG81–106D. Xenolithic core is at left, tonalitic matrix is at right, and orbicular shell is in center. Shell is divided into a feldspathic (light-colored) inner region and an outer region dominated by coarse radial hornblende (dark-colored) and plagioclase. (See text for further description.) The initial xenolith-tonalite magma interface was probably near the middle of the present orbicule shell. Scale bar is 2 millimeters.

The orbicule matrix (figure 1, right) is a tonalitic facies of the Larsen granodiorite and is composed of blocky plagioclase, biotite, diopside (largely altered to hornblende), and interstitial quartz. Tonalite magma was the heat source for partial melting of xenoliths inferred previously.

Mineral-chemical profiling of orbicular specimen TG81–106D was accomplished by electron microprobe. Ferromagnesian minerals exhibit nearly constant composition from the core through the feldspathic inner shell region of the orb. Typical compositions of specimen TG81–106D are:

- *Diopside*—$Ca_{.94}Mg_{.68}Fe_{.37}Mn_{.01}Na_{.02}Al_{.02}Si_{1.98}O_{6.00}$;
- *Biotite*—$K_{1.84}Na_{.02}Mg_{2.45}Fe_{2.55}Mn_{.03}Ti_{.47}Al_{2.63}Si_{5.57}O_{20.00}(OH,F,Cl)_{2.00}$; and
- *Hornblende* (accessory)—$Ca_{1.80}K_{.21}Mg_{2.27}Fe_{2.13}Mn_{.04}Ti_{.20}Na_{.38}Al_{1.79}Si_{6.56}O_{22.00}(OH,F,Cl)_{2.00}$.

However, associated with radial hornblende growth in the outer shell region is a distinct iron-enrichment trend in all three ferromagnesian minerals. This trend levels asymptotically into the matrix. Manganese and chlorine parallel the iron trend, but magnesium and fluorine exhibit an antipathetic profile. Typical matrix compositions are:

- *Diopside*—$Ca_{.87}Mg_{.59}Fe_{.49}Mn_{.02}Na_{.02}Al_{.03}Si_{1.97}O_{6.00}$;
- *Biotite*—$K_{1.85}Na_{.03}Mg_{2.00}Fe_{2.88}Mn_{.04}Ti_{.58}Al_{2.65}Si_{5.50}O_{20.00}(OH,F,Cl)_{2.00}$; and
- *Hornblende*—$Ca_{1.84}K_{.17}Mg_{1.92}Fe_{2.64}Mn_{.05}Ti_{.08}Na_{.33}Al_{1.74}Si_{6.65}O_{22.00}(OH,F,Cl)_{2.00}$.

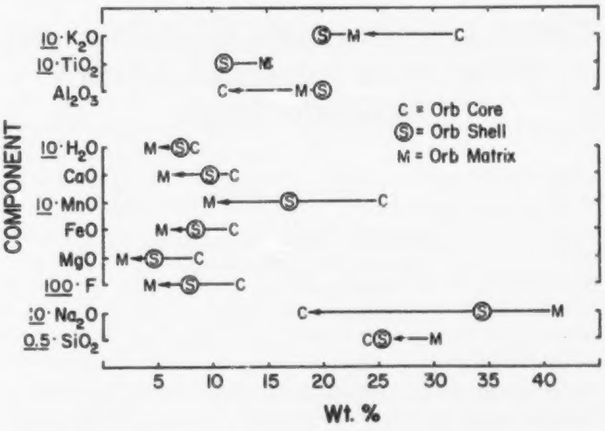

Figure 2. Core, shell, and matrix bulk compositions, calculated from electron microprobe and modal data for orbicular specimen TG81–106D. For many components, scaling factors are used so that all components may plot on the same diagram. Thus, "10·Na_2O" reads "ten times the weight percent of Na_2O," etc.

Plagioclase ranges in mean composition from 36–37 mole percent anorthite (An_{36-37}) in the core and matrix to 50 mole percent anorthite (An_{50}) in the shell region. All plagioclase exhibits normal zoning.

Whole-rock analyses of the core, shell, and matrix were calculated from electron microprobe and modal data. Whole-rock data are summarized graphically in figure 2. It is evident from figure 2 that the core is enriched in the components ferrous oxide (FeO), magnesium oxide (MgO), calcium oxide (CaO), manganese oxide (MnO), potassium oxide (K_2O), water (H_2O) (?), and fluorine (F) relative to the tonalitic matrix; the matrix is relatively enriched in sodium oxide (Na_2O), aluminum oxide (Al_2O_3), and silica (SiO_2). The composition of the shell is intermediate to that of core and matrix, for nearly all components, suggesting that the shell represents a near-linear chemical mixture of xenolith and tonalite magma.

The approximate nature of the chemical transfer between xenolith and magma can be inferred from figure 2. Extensive partial melting of diopside and biotite in the outer part of the original xenolith would contribute considerable CaO, FeO, MgO, and K_2O to the evolving partial melt. Once dissolved into the melt phase, these components would be free to diffuse in response to chemical potential (μ) gradients set up by the initial difference in xenolith and magma compositions. Because CaO, FeO, MgO, MnO, K_2O, and H_2O(?) are enriched in the (unmelted) xenolith and relatively depleted in the tonalite magma (figure 2), it is likely that diffusion of these components would be from xenolith to magma. Similarly, from figure 2, we infer that components Na_2O, Al_2O_3, and SiO_2 would diffuse from the magma to the xenolith.

This mass transfer process is postulated on the basis of an orbicule representing an intermediate stage of xenolith assimilation. However, the process, when taken to completion, also accounts for the common field occurrence of more-advanced orbicules, which have dominantly plagioclase cores (with residual xenolithic diopside ± biotite) and cafemic shells (e.g., see Dahl and Palmer 1981, figure 1). Chemical analyses and details of the mass transfer model (only briefly outlined here) will be presented elsewhere (Dahl and Palmer in preparation).

This research was supported by National Science Foundation grant DPP 80-01743.

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Cenozoic foraminiferal biostratigraphy of the MSSTS–1 drillhole, western McMurdo Sound

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The McMurdo Sound Sediment and Tectonic Studies (MSSTS) drillhole, situated 77°33′25.83″S 164°12.8′E in western McMurdo Sound, was completed during October and November 1979. Drilling commenced at a seafloor depth of 196 meters and terminated 425 meters below sea level. Basic geological, geophysical, and physical property data have been published by Pyne and Waghorn (1980). Barrett and McKelvey (1981) summarized the preliminary results obtained at this drillsite. They interpreted the entire sandstone, mudstone, and diamictite sequence as having been deposited in glaciomarine environments, "in a shallow near-shore environment close to calving debris-laden glaciers" (p. 544). These authors also provided a generalized lithologic column.

Results from the examination of foraminifera in 72 samples are presented elsewhere (Webb 1982a, 1982b, in press; Webb, Leckie, and Ward in press).

My associates and I (Webb et al. 1982, in press) used planktonic and benthic foraminifera to subdivide the 229-meter succession into six sequences (S1 through S6). Major hiatuses (H1 through H5) separate the sequences. The six sequences represent parts of the late Paleocene to early Eocene, middle to late Eocene, late Oligocene, early to middle Miocene, Pliocene, and Pleistocene to Recent. We concluded that hiatuses are of much greater duration than sequences. We estimated that no more than 19 million years of the last 56 million years are represented by sediments in this succession.

Elsewhere (Webb in press) I have proposed that each sequence and hiatus represents interglacial and glacial phases, respectively. During the time represented by each hiatus, large volumes of ice moved from the periphery of East Antarctica to the Ross Sea, deeply dissecting the emerging Transantarctic Mountains. This ice grounded in the Ross Sea, eroding deposits of the previous interglacial sequence. These Paleogene glaciations caused or contributed to global eustatic depression.

The markedly cyclic nature of Cenozoic glaciations, as determined from marine evidence, points to some connection between mountain uplift, ice damming, transmountain ice movements, glaciation at sea level, and sea level fluctuations.

If arguments for punctuated multiphase glaciation during the Paleogene are valid, we must be able to demonstrate correlative and geologically compatible events beyond Antarctica. Variations of planktonic content and diversity, paleotemperatures derived from oxygen isotope analyses of planktonic foraminifera, geographic distribution of tropical large foraminifera, and patterns of transgression and regression in Australasia can be closely correlated with the timespans of glacial (hiatuses) and interglacial (sequences) events interpreted from the MSSTS drillhole.

The arguments of Mathews and Poore (1980) for a significant degree of ice sheet development in the early Cenozoic seem warranted. In fact, the arguments of Barron, Thompson, and Schneider (1981) and Mathews and Poore for continental ice development in Cretaceous times also deserve more serious consideration.

This work was supported by National Science Foundation grant DPP 79–0743.

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Seismic refraction and reflection program in McMurdo Sound

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Shallow crustal refraction studies in McMurdo Sound begun in the 1978–79 field season were extended in 1981–82 to seismic soundings to the mantle. Observations were made from annual ice in McMurdo Sound during November and December 1981. A reversed refraction profile was shot subparallel to the coast from the McMurdo Ice Shelf on the south to the Nordenskjöld Ice Tongue on the north, for a total shot-detector distance of 200 kilometers. Following the long-refraction study, a seismic reflection profile was extended from Hut Point Peninsula near Cone Hill 13 kilometers to the west along a series of refraction profiles shot during the 1980–81 field season. Field participants included L. McGinnis, R. Bowen, T. Fasnacht, J. Rasmussin, J. Erickson, S. Silver, and S. Germanus.

The long-refraction measurements were made with shots of up to 900 kilograms and were recorded on an SIE-RS4, 12-channel refraction seismograph and a Texas Instruments DFS-III, 24-channel reflection/refraction seismograph. A series of shots was fired at the McMurdo Ice Shelf and Nordenskjöld Ice Tongue locations, and the two seismic systems were moved after each shot. Three cables were used, two with 50-meter spacings between takeouts and one with 30.48-meter spacings. Both 8¼- and 4-hertz geophones were used.

Common depth point (CDP) techniques were used for the reflection profile with 24-channel, 12-fold coverage. Shots were spaced at 50-meter intervals at the center of the spread and were placed in the water 5 meters below the surface of the sea ice. Shot size ranged from 2.27 kilograms to 9.07 kilograms. Record length varied from 7 seconds for the 2.27-kilogram shots to 10 seconds for the 9.07-kilogram shots.

Preliminary results show that McMurdo Sound is underlain by approximately 3.5 kilometers of glaciomarine and preglacial sediments resting on a crystalline basement having a mean velocity of 5 kilometers per second, similar to that for basement in the dry valleys (Wilson 1982). Basement is underlain, at depths of up to 6 kilometers, by a nonmagnetic seismic refractor having a velocity near 6.5 kilometers per second. The refractor is believed to consist of a granulitic facies petrologically similar to inclusions found on Hut Point Peninsula. The long-refraction interpretation gives a mantle depth of approximately 25 kilometers, which corresponds with Burdelik's (1981) gravity interpretation. The crust beneath the Transantarctic Mountains thickens abruptly about 15 kilometers offshore, according to the gravity model.

This research was supported by National Science Foundation grant DPP 80-19995.

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Reactions in a cooling basanite flow from DVDP borehole 2, Hut Point Peninsula, Ross Island

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In 1973, the Dry Valley Drilling Project (DVDP) drilled and cored three holes in the volcanic rocks of Hut Point Peninsula, near McMurdo Station, on Ross Island (Kyle and Treves 1974; Treves and Kyle 1973). One of the thickest units, a 43.77-meter-thick basanite flow retrieved from the second drill hole, was sampled at 2-meter intervals throughout the flow and at 25- to 40-centimeter intervals near the top and bottom. The basalt is vesicular near the top (2 meters) and shattered at the base (2.5 meters).

Clinopyroxene in this basanite is a calcic augite containing up to 7.28 percent TiO_2 (titanium dioxide) by weight and 13.58 percent Al_2O_3 (aluminum oxide) by weight. Sector-zoning is common within the top 3 meters of the flow, and many crystals display ultra colors. Overgrowths of a purplish-brown rim start to appear at a depth of 1 meter from the top and thicken toward midflow. At a depth of 4 meters, sector-zoning is replaced by patchy zoning or irregular swirls. This persists down to 12 meters, where chemical zoning and ultra colors disappear and only medium-to-small crystals in the groundmass are zoned. At a depth of 24 meters (2 meters below midflow), even medium-sized pyroxene crystals start to homogenize and become patchy. The same sequence was observed inversely in the lower half of the flow.

Highly strained olivine xenocrysts showing kink bands and undulatory extinctions, probably derived from the Earth's mantle, are dispersed throughout the flow except in a layer at depths of 10–25 meters below the top of the flow. In this region, deformation structures must have been annealed out, a process similar to that responsible for the disappearance of chemical disequilibrium in zoned pyroxene located in the hottest central part of the flow.

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Japanese earth science research in the McMurdo Sound region, 1981–1982

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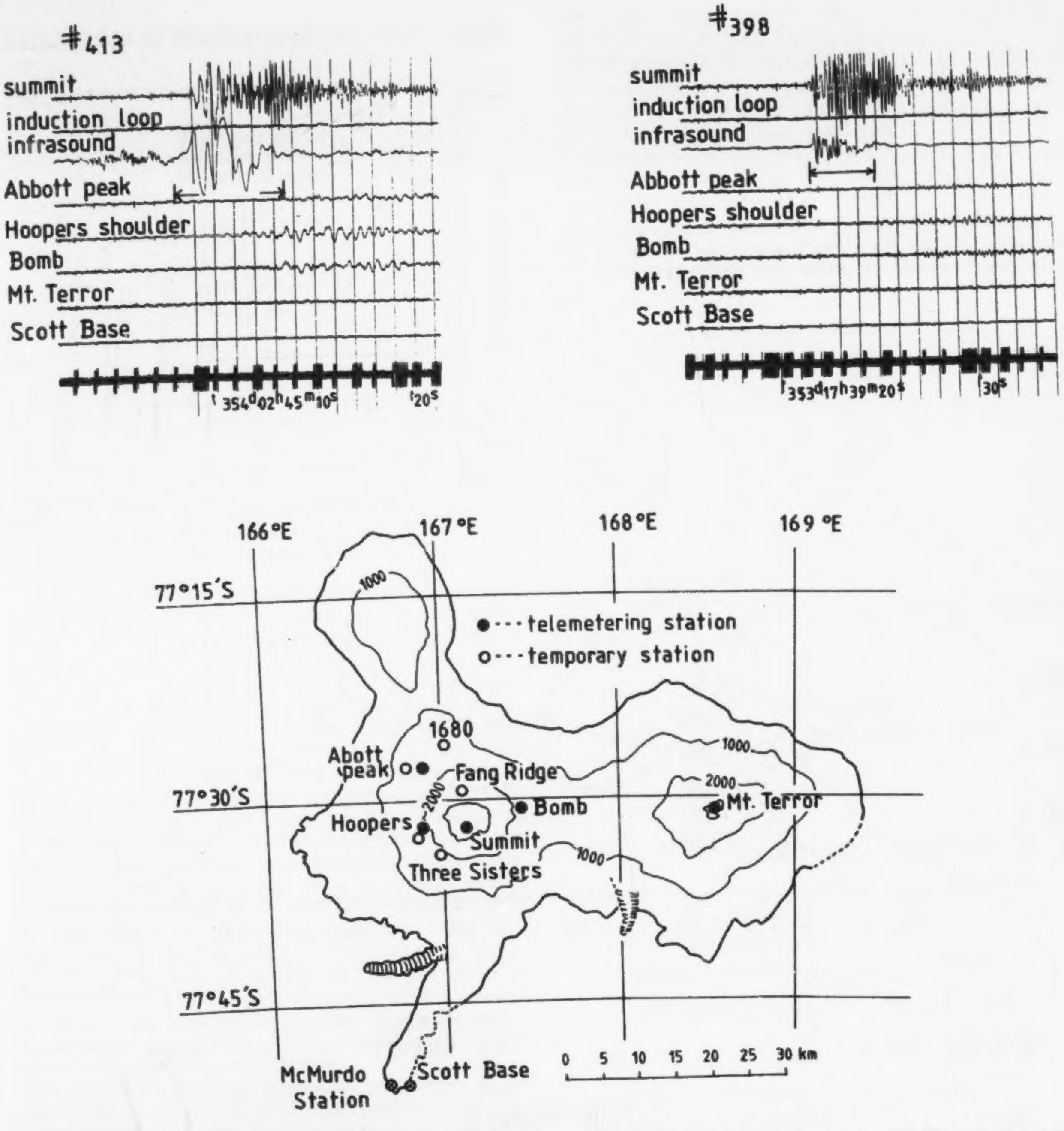
The Japanese party consisting of Kazuo Shibuya and Kei Terai (National Institute of Polar Research) and Muneo Okayama (Department of Geophysics, Hokkaido University) visited the McMurdo Sound region for cooperative research on the International Mt. Erebus Seismic Study (IMESS) project from 23 November to 30 December 1981.

Five temporary seismic stations were installed on the flank of Mount Erebus on 1–3 and 13 December and all were recovered on 22 December 1981. Taken together, these temporary stations and the four telemetering stations installed by U.S. scientists (S-081) created a densely located network for monitoring activities associated with volcanic eruptions of Mount Erebus (see map in figure 1). A densely located seismic network is essential for the structural analyses of the volcano and for precise determination of the hypocenters.

Seismic activity was monitored for 20 days. Playback of the direct analog recorders installed at the temporary stations showed intense seismic activities, especially at the Fang Ridge station. The FM-magnetic tapes containing telemetry data were played back at McMurdo Station by the Japanese party. Visigraph outputs of 512 seismic events were copied and distributed to the participants in the IMESS. The clock in the recording system at Scott Base was replaced with a new one that is more accurate and more stable, thus resulting in noise reduction and in better quality of the time base in the magnetic tapes. The FM-recording and monitor pen-recording systems were inspected for maintenance, and the seismic data are now being acquired.

Preliminary analyses of the telemetry data obtained during the 1981–82 field season show some characteristic features of the volcanic activities of Mount Erebus. The earthquakes associated with volcanic eruptions were characterized by infrasound waves at the summit station (sensor installed by R. Dibble, Victoria University of Wellington) (see events 413 and 398 in figure 1). Four types of eruptions can be distinguished on the basis of the relationship between the seismic waves and the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summit
induction loop
infrasound
Abbott peak
Hoopers shoulder
Bomb
Mt. Terror
Scott Base
354d02h45m10s
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#398
summit
induction loop
infrasound
Abbott peak
Hoopers shoulder
Bomb
Mt. Terror
Scott Base
353d17h39m20s
30s
166°E
167°E
168°E
169°E
77°15'S
77°30'S
77°45'S
● --- telemetering station
○ --- temporary station
1000
1680
Abott peak
Fang Ridge
2000
Bomb
Hoopers
Summit
Three Sisters
1000
2000
Mt. Terror
McMurdo Station
Scott Base
0 5 10 15 20 25 30 km

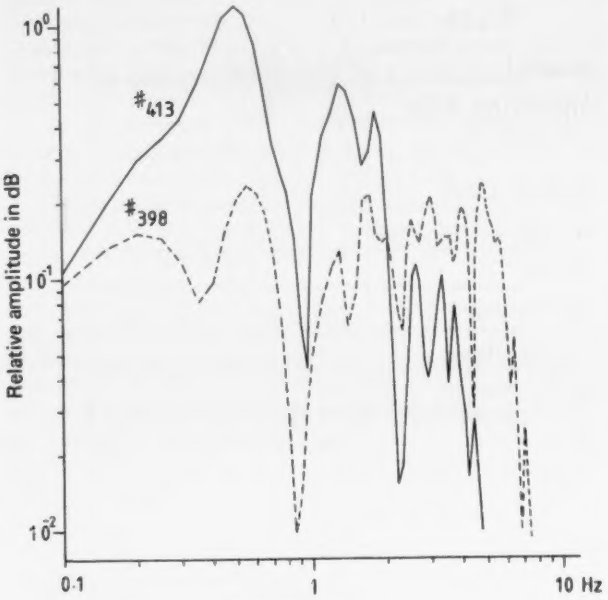
Figure 1. Upper: Examples of seismic events associated with volcanic eruptions (event 413 at 0245 on 20 December 1981 and event 398 at 1739 on 19 December 1981). The channels, except induction loop and infrasound, show seismic traces at the seismic station. At the bottom of the two charts are given IRIG-H coded time signals of about 16 seconds' duration. Lower: Location of seismic stations in the 1981–82 field season.

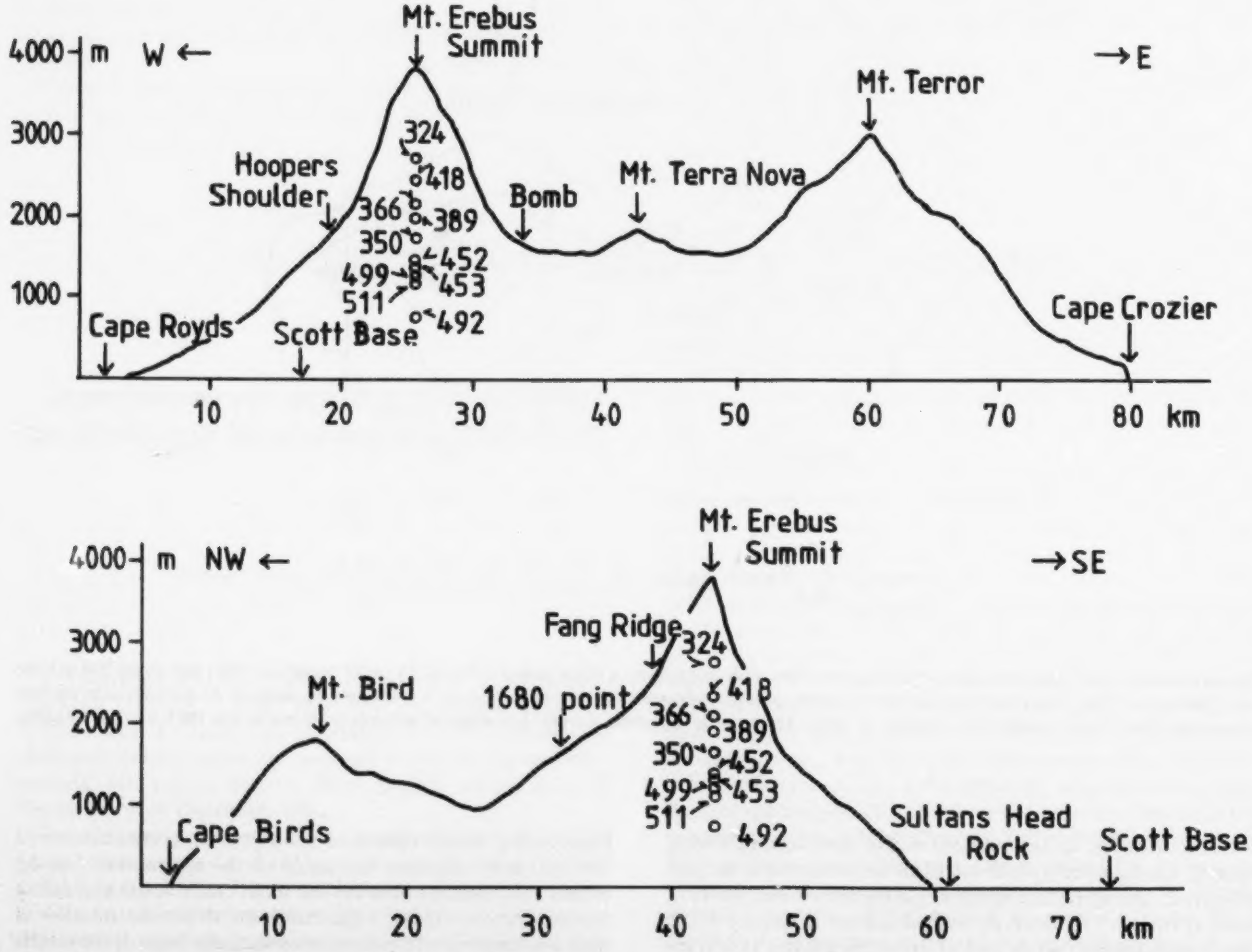
infrasound waves, as summarized in the chart accompanying figure 2. Examples of types II and III are shown in the lower part of figure 2. The amplitude spectrum of the infrasound waves of event 413 (figure 1) is relatively limited to lower frequency (0.1–2 hertz) components, while that of event 398 (figure 1) is comparatively flat up to the higher frequency component of 8 hertz. Hypocenter determination of some seismic events associated with volcanic eruptions was made on the assumption that the events were located beneath the main crater at the summit of Mount Erebus. Figure 3 illustrates the depth distribution of such events projected on two cross sections. Most of the events of Ross Island were located 1,000 to 3,000 meters above sea level.

The Division of Polar Programs of the National Science Foundation and the Antarctic Division of the New Zealand Department of Science and Industrial Research provided logistics support.

Figure 2. Below: Types of volcanic eruptions grouped by the seismic and infrasound waves. Right: Amplitude spectrum of the infrasound waves marked by the arrows in the upper portion of figure 1.

Type of eruption	Seismic wave	Infrasound wave
Type I	large	indistinct
Type II	distinct	low frequency
Type III	distinct	high frequency
Type IV	indistinct	large




4000
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Mt. Erebus Summit
Mt. Terror
Hoopers Shoulder
Bomb
Mt. Terra Nova
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418
366
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511
492
Cape Royds
Scott Base
Cape Crozier
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60
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80 km
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NW ←
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Mt. Erebus Summit
Fang Ridge
Mt. Bird
1680 point
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418
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389
350
452
499
453
511
492
Cape Birds
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Scott Base
10
20
30
40
50
60
70
km

Figure 3. Depth distribution of seismic events associated with volcanic eruptions of Mount Erebus.

Seismicity of Mount Erebus, 1981–1982

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In December 1980, a permanent tripartite array of vertical, short-period, seismic stations was installed on Mount Erebus (Kienle et al. 1981). This array was expanded by two stations on 19 and 20 November 1981, when one station was added in the saddle between Mount Erebus and Mount Terra Nova and another near the summit of Mount Terror. All signals are radio-telemetered continuously to Scott Base. In December 1981, a local seismometer was installed in the vault of the Scott Base station of the World Wide Standard Seismograph Network (WWSSN). Station locations, elevations, very-low-frequency (VLF) transmitter frequencies, and the basic electronic layout of the array are shown in figure 1. The Mount Erebus summit station relays three different signals—one seismic channel, one acoustic channel to monitor explosive gas discharges from the vicinity of the lava lake in the inner crater, and one experimental channel that is being used to look for magnetic signals. These latter signals might be expected if eruptions of conducting magma pass through the Earth's static magnetic field. The sensor for this experiment is a figure-eight induction loop laid out around the summit crater. High- and low-gain data are recorded continuously on a slow-speed magnetic tape recorder and on a single-channel ink pen recorder at Scott Base.

The system has performed beyond our expectations for the past 2 years, running unattended from December 1980 to the end of July 1981, when the gel-cell batteries it uses ran down. These cells were set up to be trickle-charged by solar panels, and it was particularly gratifying to see the stations gradually come back on the air in September 1981 as daylight increased enough to recharge the batteries. During station servicing in December 1981, the Erebus summit station, which had sustained minor damage during the previous winter, was repaired; the other two stations survived their first winter undamaged. After servicing, the complete set of five stations operated continuously until 31 May 1982, when the Abbott station went off the air. Bomb station stopped transmitting in mid-July. The stations at Erebus summit, Hoopers Shoulder, and Mount Terror were still working as of 4 August 1982, according to Ross Mason, the electronic technician at Scott Base. Mason also reported that during an unusually bright twilight in early August, Abbott and Bomb stations resumed transmission for a brief period, indicating that exhausted batteries were the reason for their earlier failures. During the depth of winter, temperatures drop well below −40°C and wind speeds can exceed 80 knots on the flanks of Mounts Erebus and Terror.

Seismicity on Mount Erebus has been quite high, usually exceeding 10 events per day. The earthquakes typically occur in swarms, a characteristic of the seismicity of active volcanic regions. Particularly notable swarms took place in April and July 1981, when daily counts exceeded 100 and on one day exceeded 150. During such peaks of activity more than 20 events per hour

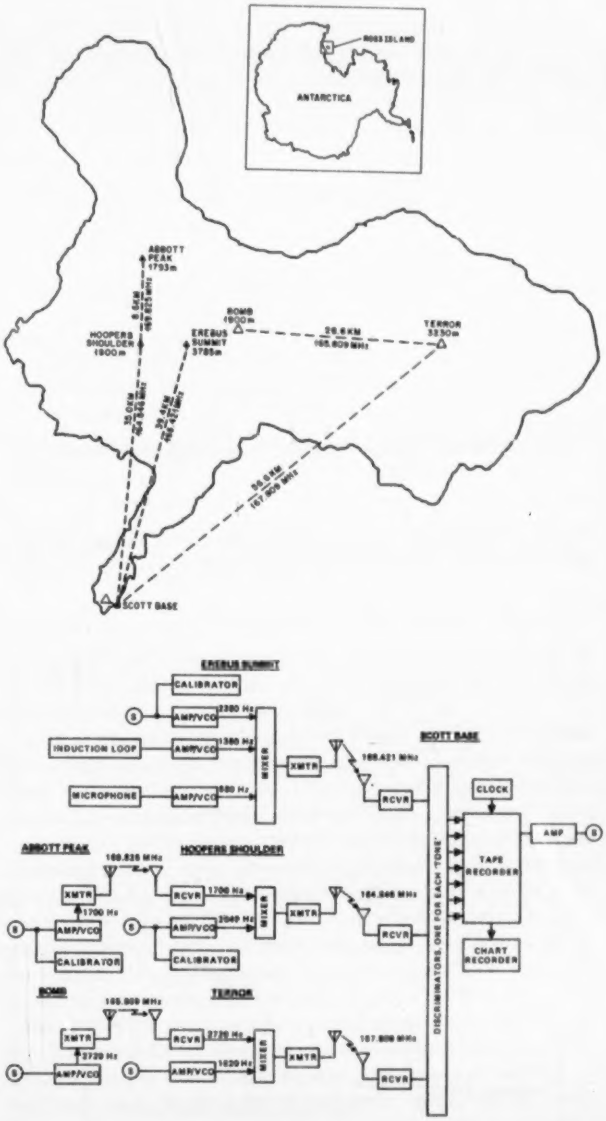
ROSS ISLAND
ANTARCTICA
ABBOTT PEAK 1793m
HOOPERS SHOULDER 1900m
EREBUS SUMMIT 3785m
BOMB 1900m
TERROR 3230m
29.6KM
165.809 MHz
56.6KM
167.909 MHz
SCOTT BASE
EREBUS SUMMIT
CALIBRATOR
AMP/VCO
2380 Hz
INDUCTION LOOP
1380 Hz
MICROPHONE
680 Hz
MIXER
XMTR
168.421 MHz
RCVR
SCOTT BASE
CLOCK
TAPE RECORDER
AMP
S
CHART RECORDER
DISCRIMINATORS, ONE FOR EACH "TONE"
ABBOTT PEAK
169.825 MHz
HOOPERS SHOULDER
1700 Hz
2040 Hz
164.948 MHz
BOMB
165.909 MHz
TERROR
2720 Hz
1020 Hz
167.909 MHz

Figure 1. Top: Locations, altitudes, and transmitter frequencies of five permanent seismic stations on Mount Erebus and Mount Terror. Bottom: Schematic block diagram of seismic system. S = seismometer; AMP/VCO = amplifier/voltage controlled oscillator; XMTR = transmitter; RCVR = receiver.

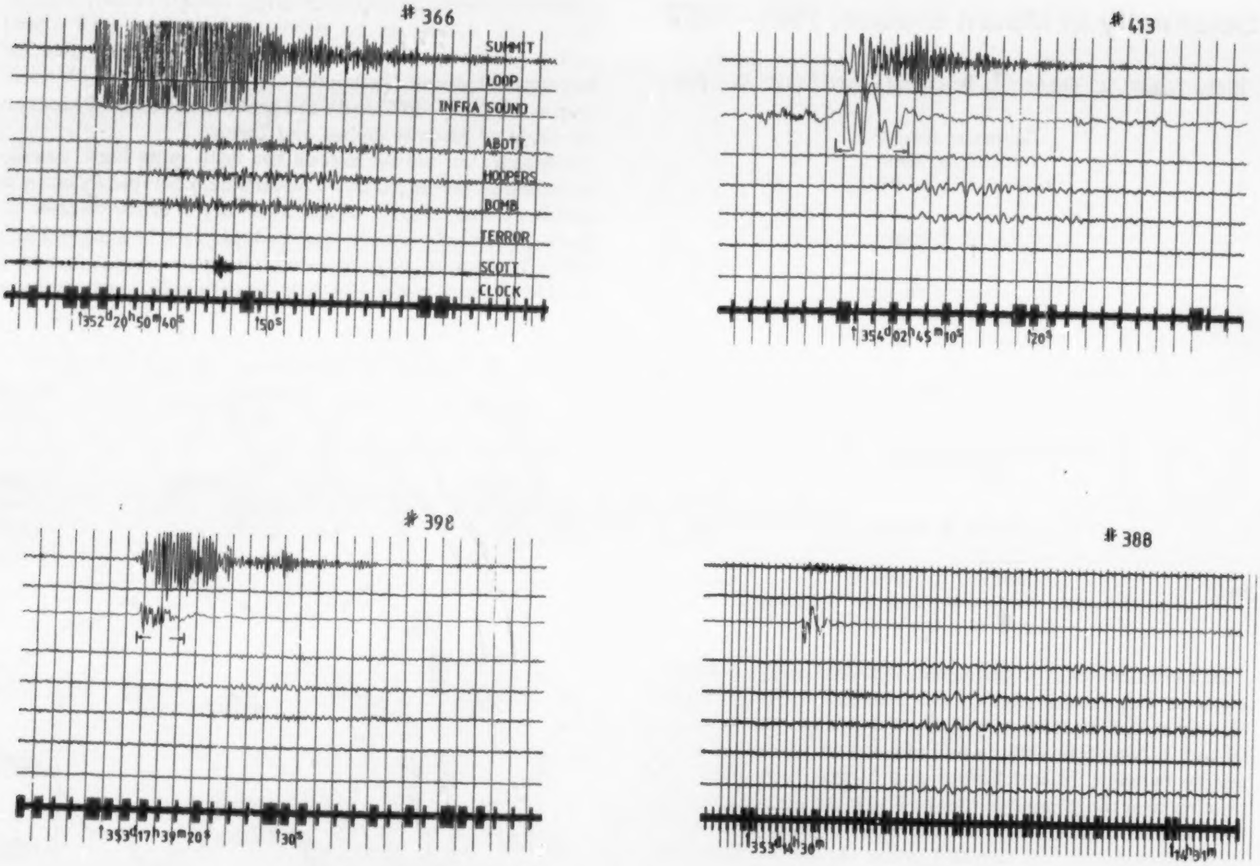

Figure 2. Seismic and acoustic signatures of four volcanic eruptions. Vertical lines mark seconds. Gains are the same for all four events. Time intervals marked by arrows on the sonic trace (events 412, 398) have been analyzed to obtain relative amplitude spectra.

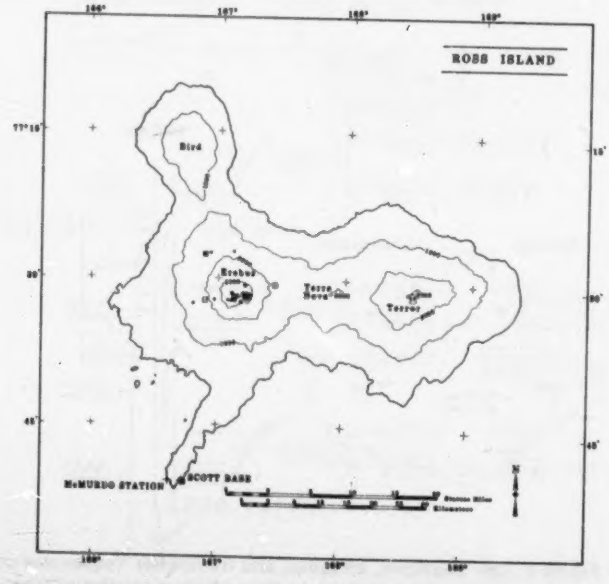

Figure 3. Epicenters for larger events recorded 10–22 December 1981. Stars represent earthquakes with infrasound (explosions?); solid dots represent tectonic or other seismic events (icequakes?); seismic stations shown as open squares.

are recorded. Earthquakes associated with swarms are characterized by sharp onsets and wave codas of less than 10 seconds, implying that the source region lies very close to the station. Mason reported from Scott Base in August 1982 that an earthquake swarm lasting 3 days started about 10 July 1982, with small tremors being recorded at a rate of one per minute.

The acoustic sensor on the summit crater rim of Mount Erebus has been extremely valuable in helping distinguish volcanic explosions from tectonic earthquakes and from other seismic sources, such as icequakes. Gas discharges and explosions occur daily. Scientists camped at the summit hut typically hear about 3–6 explosions of varying intensity per day. Sound qualities range from "rumbles," through both "short and prolonged roars," to "sharp bangs." Infrasonic and seismic recordings of Erebus eruptions also show several distinctly different signatures (figure 2). We are not sure of the absolute levels of seismic and acoustic energy partitioning, but the signatures nevertheless allow a crude classification of the eruptions. For example, event 366 in figure 2 shows a strong seismic signal and a very weak acoustic trace, while event 388 shows exactly the opposite relationship. Events 413 and 398 have similar seismic signatures but quite different infrasound amplitude spectra. While the infrasound spectrum for event 413 has a relatively sharp, high frequency cutoff at 2 hertz, event 398 contains higher frequencies and the cutoff occurs at 7 hertz. We do not yet understand the significance of these differences, but we believe they are related to the depth, energy release, and mechanism of various types of eruptions that are transitional between the two end members, that is, between less violent gas emissions (roar, without explosive onset) and more violent, sharp explosions (bang, explosive onset). These source characteristics are being investigated by the New Zealand and Japanese team members (e.g., Dibble 1981).

A positive correlation of signals seen on the figure-eight induction loop with volcanic explosions has been noted. The origin of these signals could be twofold: (1) eruption of conducting magma or ionized gas in the Earth's static magnetic field, and (2) expansion of the area enclosed by the wire loop as the summit crater dilates during explosions. We do not know yet which of these processes is more important. Unfortunately, a volcanic bomb thrown beyond the crater rim during a large explosion severed the wire in early December 1981, temporarily suspending the induction experiment. The break was located and repaired on 23 January 1982.

Earthquake location has thus far proved difficult because larger magnitude local events that produce clear body-wave arrivals at all stations are extremely rare. The local magnitude range of events recorded in 1980–81 was as low as -0.5 to -2.8 (Dibble 1981). Typically, we can use only the four stations located on Erebus, plus Abbott, Hoopers Shoulder, Bomb, and Summit stations, to locate earthquakes. Terror and Scott Base stations rarely registered useful information. Exact arrival times are usually hard to determine because of the highly attenuated, emergent onset of most of the signals. Another problem is the ill-known velocity structure of Mount Erebus. On the basis of teleseismic data, we have adopted 4.5 kilometers per second as an average *P*-wave velocity from sea level to the summit. This velocity was used to locate the selected events shown in figure 3. As expected, many of these better recorded events were located centrally beneath the summit crater of Erebus, with depths ranging from very near the surface to usually less than 3,000 meters below the summit crater. Two kinds of earthquakes can be distinguished in figure 3—those with and those without infrasound signals, the former representing explosions. There is a tendency for the epicenter to scatter along an east-west trend across the summit of Mount Erebus, parallel to the Erebus-Terra Nova-Terrror volcanic axis. This trend was also observed in the previous season (1980–81) (Takanami et al. 1981). The data suggest that the feeder dike or dikes of the Mount Erebus lava lake may have an east-west orientation.

In summary, over the past 2 years we have observed a high level of very-small-magnitude earthquake activity associated with volcanic processes near the summit of Mount Erebus. Swarm-type activity is typical. An unresolved question is whether or not the few events occurring on the outer flanks of the Erebus volcano are truly tectonic or are icequakes. Fang Glacier may be the source of some of these events.

This work was supported by National Science Foundation grant DPP 79-23016. We are very much indebted to the Scott Base personnel, in particular to Stan Whitfield and Ross Mason, who have kept the recording system running through the winter months. Special thanks must also go to the VXE-6 helicopter crews who flew us to some rather hostile places. Bill McIntosh, Kei Terai, Muneo Okayama, and Nick Cradock (New Zealand Antarctic Research Program) were invaluable assistants.

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Volcanic activity of Mount Erebus, 1981–1982

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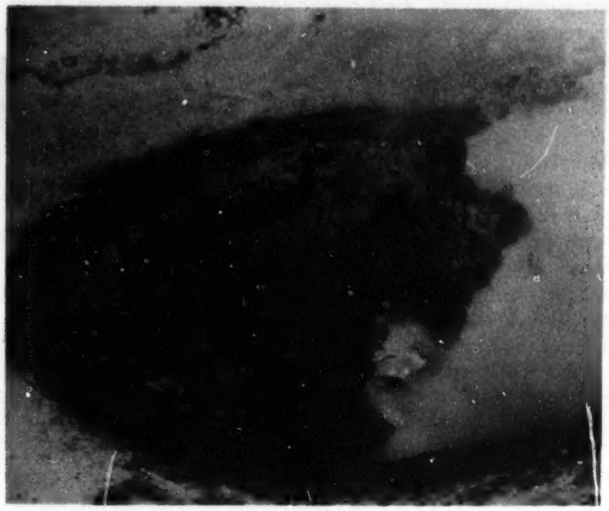
The anorthoclase phonolite magma lake at Mount Erebus has been under surveillance since its discovery, by New Zealand Antarctic Research Program (NZARP) personnel, during the 1972–73 austral summer field season (Giggenbach, Kyle, and Lyon 1973). A summary of the volcanic activity up to and including the 1976–77 field season was published recently (Kyle et al. 1982). Volcanic activity since 1976 has been summarized in various reports in the *New Zealand Volcanological Record*, the *Bulletin of Volcanic Eruptions*, and the *Antarctic Journal of the U.S.* (Kyle 1979, 1981; Kyle and McIntosh 1978).

Annual observations are made to record changes in the behavior and nature of the magma lake and to collect volcanic ejecta for petrologic studies. Over the last 5 years, volcanic activity has remained fairly constant. During observations between 3 and 13 December 1981, small strombolian explosions continued at a frequency of four to six per day. The eruptions are believed to originate from the active vent adjacent to the lake. Many fresh volcanic bombs were found on the crater rim, suggesting that the eruptions were the strongest observed in the last 3 years. This may reflect an increase in distance between the lip of the active vent and the underlying magma level.

Since 1976 the magma lake has remained fairly constant in size. It is about 120 meters long and oval in shape, and it usually shows a simple convection pattern, with magma welling up from two centers about one-third of the way from each end. Downwelling occurs around the edge of the lake and along a zone roughly in the middle of the lake.

Although the surface area of the lake appears to have remained constant, the level of the lake relative to the crater rim appears to be descending slowly. Changes are difficult to monitor but are estimated to be as much as 5–10 meters over the last 3 years. The lowering of the level may be equivalent to the amount of material ejected by the small strombolian eruptions. A deformation survey pattern set up in December 1980 was remeasured in December 1981; preliminary data indicate a contraction in the size of the crater rim, consistent with lowering of the magma column. Lowering is also suggested by the development on the main crater floor of a semiradial fracture which parallels the inner crater rim. The main crater floor apparently is slowly collapsing into the inner crater. See figure.

Work at Mount Erebus was supported by National Science Foundation grants DPP 79–20316 and DPP 80–20002. The untiring assistance of Bill McIntosh is gratefully acknowledged.



Infrared view of the inner crater at Mount Erebus taken from the east rim of the main crater. The magma lake is in the lower right quadrant. White areas of the lake are at the highest temperature (about 1,000°C) and are areas of exposed magma; grey and dark areas have a thin crust of congealed magma.

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Thermal imagery of Mount Erebus from the NOAA–6 satellite

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The National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites provide a good perspective for viewing and monitoring Mount Erebus, an active antarctic volcano. Mount Erebus (3,794 meters) is situated at 77°32'S 167°09'E. Field investigations and aerial reconnaissance indicate the presence of an active lava lake in the main crater. The lava lake is approximately 40 meters in diameter and is within an inner crater 250 meters in diameter on the main crater floor (Kyle et al. 1982). Kyle and others (1982), using a geothermometer for estimating lava lake temperature and an optical pyrometer for direct measurements, found the temperature to be approximately 1,000°C. They also indicate that subsequent crustal formation over the lava has reduced the temperature to about 500°C. Strombolian eruptions occur in varying frequency, from as many as 3 eruptions per day in January 1978 to 1.6 per day in early 1979 (Kyle 1979).

The NOAA series of satellites are sun synchronous and polar orbiting. They provide at least twice-a-day coverage of any given area at an average altitude of 833 kilometers. Aboard NOAA–6 (which provided the data discussed in this article) the main sensor system is the advanced very high resolution radiometer (AVHRR). This four-channel system operates in the following wavelengths:
- channel 1—0.58–0.68 micrometer (visible);
- channel 2—0.72–1.1 micrometer (near infrared);
- channel 3—3.55–3.93 micrometer (infrared); and
- channel 4—10.5–11.5 micrometer (thermal infrared).

Resolution of each channel is 1.1 kilometers at the satellite subpoint (Hussey 1979).

The lava lake atop Mount Erebus seems to be detectable with the NOAA–6 AVHRR sensor even though it is a subresolution feature. Using channel 3, Matson and Dozier (1981) have detected subresolution scale sources of very high temperature. Using an algorithm developed by Dozier (1981), they have shown that the size and black-body temperatures of these sources can be calculated. This technique has provided a basis for reviewing thermal imagery data collected at McMurdo Station in 1980. The taped data were computer-enhanced and enlarged, and 1:1,000,000-scale images of Ross Island were prepared. Figure 1 is an example of the results of this work. This channel-3 image shows a hot spot (dark) on the site of the Mount Erebus crater. Figure 2, by comparison, is a Landsat multispectral scanner (MSS) image of the same area taken in January 1974. The 80-meter Landsat resolution provides an excellent image of the details of Mount Erebus. However, Landsat does not include thermal data as the NOAA satellites do. A digital trace (figure 3) over the crater area on the computer-

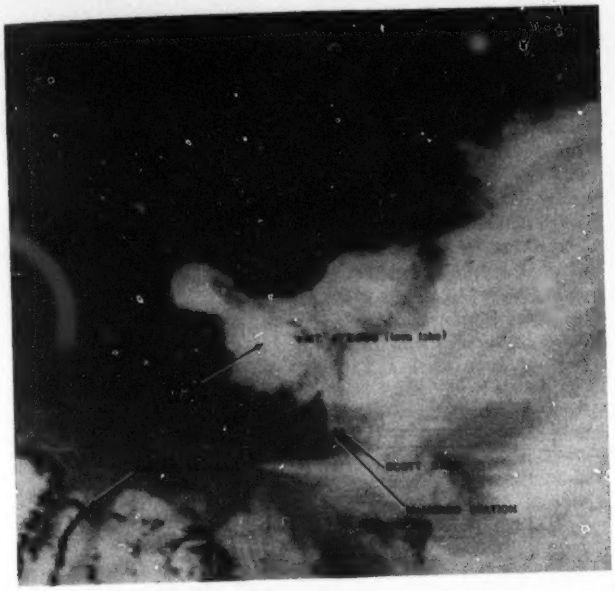

Figure 1. AVHRR thermal image (channel 3) of Ross Island taken 10 February 1980. Ground resolution is 1.1 kilometers. The black spot is the crater area of Mount Erebus (in this rendition, cold areas are shown as white and warm areas are shown as dark). Scale, 1:1,000,000.

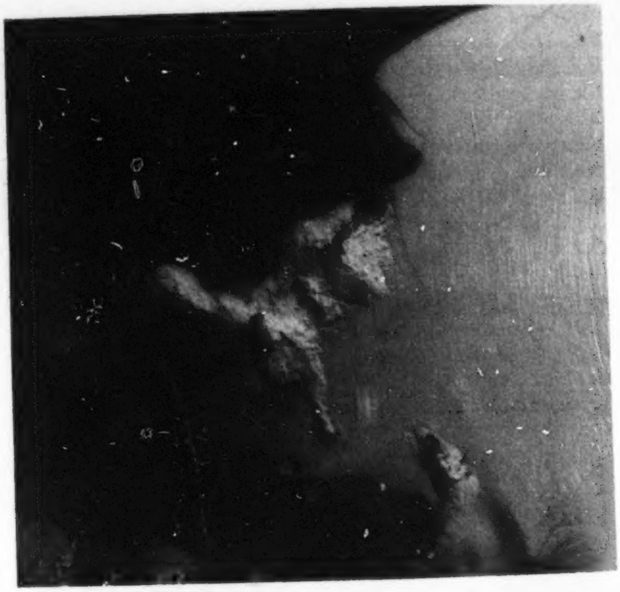

Figure 2. Landsat (80-meter resolution) multispectral scanner (MSS) image of Ross Island taken 5 January 1974. Summit crater of Mount Erebus is seen as snow-free. Scale, 1:1,000,000.

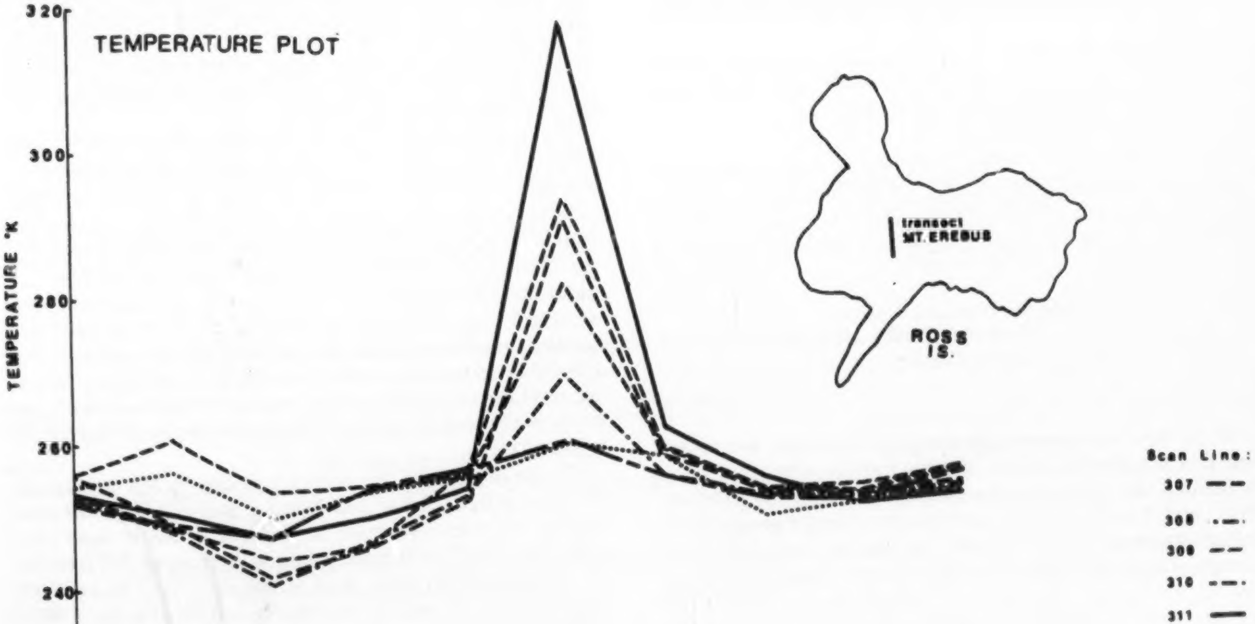

Figure 3. Satellite trace of surface temperature over Mount Erebus. The pixel that includes the crater is about 50°K warmer than the area surrounding the crater. As the pixel is larger in diameter than the crater (1,100 meters compared with 250 meters), the cooler rocks and ice surrounding the crater also contribute to the measured temperature of the pixel. The temperature determined by the satellite sensor is thus less than the actual temperature of the crater area.

enhanced image reveals the temperature of the surface and the brightness temperature of the crater area. The trace indicates that the brightness temperature is approximately 60°K above the background at the summit, which woud include the lava lake. Since this is a subresolution feature, cooler surfaces within the same picture element, or pixel, are also contributing to the pixel radiant temperature. The resulting pixel temperature is thus less than the true brightness temperature of the crater area.

The installation of the high resolution picture transmission (HRPT) system at McMurdo Station makes it possible to monitor the thermal regime at Antarctica, including anomalous thermal areas such as Mount Erebus, in a way that was previously impossible. Its near-polar location allows many additional passes per day, greatly increasing the probability of receiving cloud-free imagery.

We extend special thanks to Jann Knapp for her cartographic assistance, to Mike Matson for his help with the temperature plot, and to John Pritchard for the enhanced imagery.

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Eruptive potential of volcanoes in Marie Byrd Land

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Those who study young volcanoes frequently are asked about the eruptive potential of these volcanoes, even when they are located in a region as remote as Marie Byrd Land. In Marie Byrd Land, human hazard is not a concern, but the possibility of climatic impact interests scientists beyond the immediate community of antarctic geologists. Volcanologists commonly try to predict the future behavior of a volcano on the basis of its history, which in temperate regions often can be determined from historical records and carbon-14 dating of organic remains buried by volcanic deposits (see, for example, Crandall, Mullineaux, and Rubin 1975). In Marie Byrd Land, however, there is no history of human observation and no organic material for carbon-14 dating. Moreover, the rate of erosion of lava is so slow that even 10-million-year-old volcanoes are deceptively fresh in appearance.

The methods available for inferring the eruptive potential of volcanoes in Marie Byrd Land are studying the emission of volcanic gasses, determining the potassium-argon (K-Ar) age of volcanic deposits, and examining ash layers in ice cores. Emission of steam from volcanic vents has been observed in Marie Byrd Land (figure and table), and the intermittent emission of steam can be inferred where fumarolic ice towers (produced by condensation and freezing of water vapor) occur around a crater rim (LeMasurier and Wade 1968).

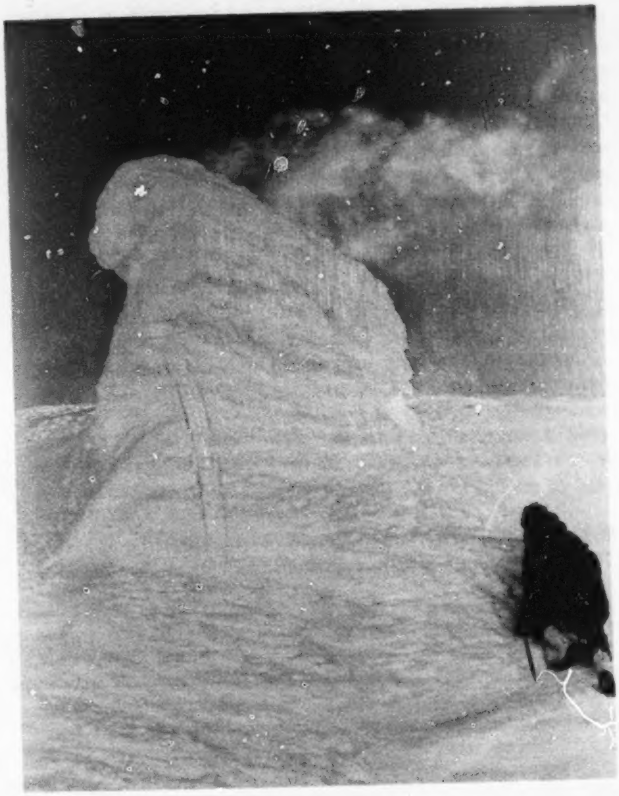
The K-Ar method of dating is not nearly as useful as the carbon-14 method for determining the very recent behavior of a volcano, because the precision of the K-Ar method decreases rapidly in materials younger than 500,000 years, whereas the carbon-14 method is most precise when used on materials only a few thousand years old or younger. Thus, in the table, the materials in the columns labeled "Less than 200,000 years" were essentially too young to be dated by the K-Ar method. It is certainly possible to date some materials that are younger than 200,000 years by K-Ar, under favorable circumstances (Dalrymple and Lanphere 1969), but the materials from Marie Byrd Land could not be accurately dated if they were younger than 200,000 years old.

On the other hand, the record provided by ash layers in the ice cores at Byrd Station and Dome C makes it clear that some volcano or volcanoes have been active in Marie Byrd Land within the past 75,000 years. Gow and Williamson (1971) recorded 25 bands of ash in the Byrd Station core, with an especially large number of bands in the interval estimated to be 16,000 to 30,000 years old. Prevailing wind directions and the coarseness of the ash virtually require a source among the Marie Byrd Land volcanoes (Gow and Williamson 1971), and the petrographic characteristics of the ash support this inference (LeMasurier 1972). Similarly, Kyle and others (1981) analyzed ash estimated to be 25,000 years old from the Dome C core and inferred its source to be Mount Takahe. The new K-Ar data that provide the basis for this paper do not invalidate any of the earlier conclusions; they simply provide a basis for a wider range of speculation about which volcanoes have erupted in the recent past and which ones are likely to erupt in the future.

Some characteristics of the evolutionary history of individual volcanoes can be used to refine the information available from K-Ar dating. Hawaiian volcanoes are known to have evolved through an initial, relatively rapid, shield-building phase, followed by the development of a summit caldera and, in turn, by the eruption of small cinder cones after the caldera formed (MacDonald 1972). A similar history seems to have characterized the development of volcanoes in Marie Byrd Land, though the time scale apparently is very much longer there than for Hawaiian volcanoes. Recent K-Ar data (LeMasurier and Rex in preparation) suggest that Marie Byrd Land volcanoes go through an initial trachytic, shield-building phase that may last roughly 0.5–2.5 million years. This is followed by caldera formation and then by a period of very infrequent basaltic cinder cone activity that may last as long as 10 million years. Thus, if the pre-caldera lavas in these volcanoes are very young, the chances for a major eruption would seem to be relatively high, particularly if the volcano displays fumarolic activity like that at Mount Berlin. On the other hand, very recent cinder cone activity, like that at Mount Andrus, is not especially suggestive of a high potential for future activity, because cinder cone activity represents the waning stage and possibly the termination of activity at a particular volcano. The pre-caldera lavas at Mount Andrus, for example, are more than 10 million years old. Mount Bursey has a similar history.

The table summarizes the available information on relatively recent manifestations of volcanic activity in Marie Byrd Land. In our estimation, the volcanoes that have very young pre-caldera rocks have the highest potential for future eruptive behavior. Hence, the farther to the right a volcano is listed on the table, the greater its potential for future activity is presumed to be. It should be noted that even a major eruption here is not likely to have much climatic impact. Very little subaerial ash has been produced by eruptions of these volcanoes in the past, and the possibility of large volumes of ash being injected into the stratosphere during future eruptions seems very slight (LeMasurier 1972).

About 18 major volcanoes in Marie Byrd Land have formed within the past 10 million years. Small-scale cinder cone activity is possible on any of these, if the eruptive histories of Mount Andrus and Mount Bursey are reasonably representative, but the next cinder cone eruption might take place on a volcano that has been dormant for 2 to 5 million years. Therefore, it probably



Actively steaming fumarolic ice tower situated on the west rim of Berlin Crater, Mount Berlin, December 1977.

Indications of potential activity in the volcanoes of Marie Byrd Land

Method	Observation			
Direct observation	Fumarolic ice towers		Actively steaming vents	
	Mt. Berlin (135°50′W 76°03′S). Observed in 1967 (LeMasurier and Wade 1968) and again in 1977.		*Mt. Berlin.* On 22 Nov. 1977, 6 witnesses observed 4–6 vents. Visited a second time within the following 2 weeks and observed 2 steaming vents.	
	Mt. Hampton (125°50′W 76°50′S). Observed in 1967 (LeMasurier and Wade 1968), but has not been revisited since.		*Mt. Kauffman* (132°30′W 75°35′S). On 11 Dec. 1977, 6 witnesses observed 3–4 steaming vents on the north flank of the volcano.	
K-Ar dating	Cinder cones		Pre-caldera rocks	
	<1 million yrs.	<200,000 yrs.	<1 million yrs.	<200,000 yrs.
	Huff Peak, Mt. Bursey (132°40′W 76°00′S)	*Mt. Andrus* (132°20′W 75°50′S)	*Shepard Island* (132°40′W 74°25′S)	*Mt. Takahe* (112°00′W 76°15′S)
	Mt. Obiglio, Grant Island (131°50′W 74°28′S)	*Mt. Waesche* (127°00′W 77°10′S)	*Mt. Murphy* (111°00′W 75°20′S)	*Mt. Berlin*
			Toney Mountain (116°00′W 75°50′S)	
			Mt. Waesche	

is not unreasonable to represent the volcanoes that have pre-caldera lavas less than 1 million years old as "active," and the remaining ones that are less than 10 million years old as dormant. A more conservative representation might show only Mount Berlin as active, because of multiple evidences of recent activity, and the remaining Plio-Pleistocene volcanoes as dormant. The only visit to the summit of Mount Takahe, where fumarolic activity is most likely to be found, was described by Anderson (1960). No fumarolic activity was reported by Anderson's party, nor by a reconnaissance survey of the lower flanks of the mountain in 1968. To our knowledge, the summit calderas of Mount Waesche, Toney Mountain, and Mount Murphy have never been searched for evidence of fumarolic activity.

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Geology, paleontology, and bibliography of the Ellsworth Mountains

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Considerable progress was made during the past year in the investigation of the large volume of information, rocks, minerals, and fossils collected during the 1979-80 Ellsworth Mountains expedition. Data and material collected on earlier expeditions to this area also were examined. These studies, coordinated among more than 25 senior investigators, involve structural, stratigraphic, paleomagnetic, paleontological, sedimentological, and geomorphic aspects of the Ellsworth Mountains. All of the 17 fossil localities sampled during the 1979-80 season and all stratigraphic units are being studied. A noteworthy recent accomplishment is the completion of a major revision of the lower 7,800 meters of the stratigraphic column (that is, subdivision of the Heritage Group and overlying Minaret Formation into formations and members).

Several significant publications have already resulted from the 1979-80 field project in the Ellsworth Mountains, and many others are in various stages of preparation. A bibliography compiled for use in planning meetings prior to the field season has been updated to include all known literature concerning geologic investigations in the Ellsworth Mountains as well as popular literature and literature on mountaineering.

Titles of papers for the Fourth International Symposium on Antarctic Earth Sciences (Adelaide, Australia, August 1982) are included, as are the citations for 13 papers given at a symposium on the geology of the Ellsworth Mountains organized and chaired by C. Craddock, G. F. Webers, J. F. Splettstoesser, and M. D. Turner as a half-day session at the 1982 annual meeting of the Geological Society of America (GSA) (New Orleans, Louisiana, October 1982). Only abstracts are printed for the GSA papers, but first drafts of complete manuscripts for most of them were submitted by the authors at the time of the New Orleans meeting. These papers, and about 10 to 15 more, will make up a volume on the geology and paleontology of the Ellsworth Mountains, being edited by C. Craddock, J. F. Splettstoesser, and G. F. Webers for the Memoir Series of the Geological Society of America. It is intended to include colored geologic maps of the entire range as plates.

An abridged version of the bibliography is presented here; an unabridged version, including more than 100 citations, some with annotations, is also available (on request from G. F. Webers). In the unabridged version, annotations are included for some of the entries because their titles do not indicate relevance to the Ellsworth Mountains. For example, the Schopf and Long article (1966; see bibliography), which includes analyses of three samples of coal from the Polarstar Formation (the only known published analyses of coal from the Ellsworth Mountains), would not have been indexed in *Antarctic Bibliography* to the Ellsworth Mountains but certainly would be useful to an investigator researching material from that area.

The unabridged version of the bibliography was compiled primarily as an aid to investigators who are preparing manuscripts for the proposed volume mentioned previously, but, as noted, it is available to others. The bibliography is stored on a word processor disk at the Minnesota Geological Survey. It would be appreciated if readers would report any corrections or additions to either of the authors.

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Mount Poster Formation, southern Antarctic Peninsula and eastern Ellsworth Land

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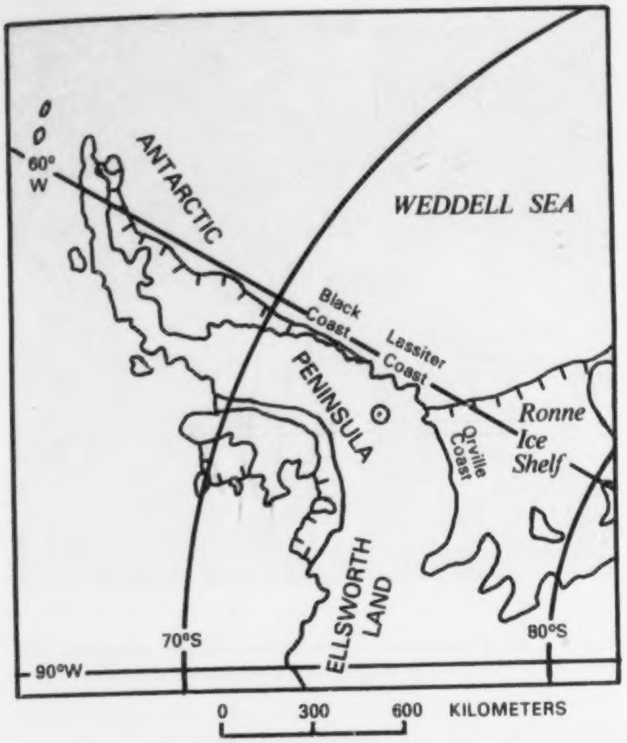
Throughout the Antarctic Peninsula and eastern Ellsworth Land, calc-alkaline volcanic and plutonic rocks of Mesozoic and Tertiary age formed during eastward subduction of oceanic lithosphere of the Pacific plate along the western margin of Gondwanaland prior to and during plate breakup. The igneous rocks record the development of a magmatic arc that had different pulses of activity. The volcanic rocks are included within the Antarctic Peninsula Volcanic Group (Thomson 1982b) of Early Jurassic to Tertiary age (Thomson and Pankhurst 1982). The group contains rocks of different facies, ages, and plate-tectonic settings whose stratigraphic relations and upper and lower contacts are not well known. This article proposes a formation name for volcanic rocks of the group that formed during a Jurassic pulse (Rowley 1978; Rowley and Williams 1982).

The Mount Poster Formation is herein defined for a sequence of volcanic rocks and sparse sedimentary rocks that underlie mostly axial parts of the southern Antarctic Peninsula and eastern Ellsworth Land. The first formation proposed for the Antarctic Peninsula Volcanic Group, it occurs in the southern part of the area underlain by the group. The volcanic rocks in this area were described but left unnamed by Williams and others (1972), who also proposed the name Latady Formation for exposures in the Latady Mountains of contemporaneous sedimentary rocks. The type locality for the volcanic rocks is at Mount Poster (74°12′S 65°20′W), west of the Latady Mountains in the southwestern Lassiter Coast (figure).

Mount Poster is a peak on the western end of an east-trending ridge about 3 kilometers long. As elsewhere in the general area, the rocks are folded and strike parallel to the Pacific margin; most beds at the type locality dip steeply northwest. The eastern part of the ridge consists of siltstone, sandstone, and slate of the Latady Formation, in which lava flows and ash-flow tuffs are interbedded. Mount Poster consists of volcanic rocks at least 600 meters thick, which overlie the sedimentary rocks exposed in the eastern part of the ridge; these sedimentary rocks are considered distal, lower parts of the Latady Formation. Most volcanic rocks in the type locality are dark-grayish-green andesitic to dacitic lava flows and ash-flow tuff. Light-gray and tan, thinly bedded, rhyodacitic air-fall and water-laid tuff, gray volcaniclastic sandstone and siltstone, and grayish-green dikes and volcanic breccia also occur at Mount Poster. Most rocks are in beds 1 to 10 meters thick and have undergone chlorite-grade metamorphism.

Ash-flow tuff at the type locality contains phenocrysts of plagioclase, subordinate embayed "beta" quartz, subordinate to minor sanidine, sparse iron-titanium (Fe-Ti) oxides, and sparse metamorphosed ferromagnesian minerals (apparently mostly hornblende). Most lava flows contain sparse phenocrysts of hornblende, plagioclase, and Fe-Ti oxides in an aphanitic groundmass. Air-fall tuff beds contain glass shards that have been recrystallized to fine-grained quartz.

Volcanic rocks of the Mount Poster Formation are widely exposed in northwestern parts of the southern Black Coast (Rowley 1973; Rowley et al. in press; Rowley and Williams 1982), Orville Coast (Rowley 1978), and eastern Ellsworth Land (Laudon 1972; Laudon et al. 1969; Rowley 1978). Volcanic rocks of similar lithology and setting in the west-central Black Coast



Index map showing the Antarctic Peninsula and eastern and central Ellsworth Land. Location of Mount Poster shown by the circled dot in the southern Antarctic Peninsula. Latady Mountains lie just east of Mount Poster. Edges of ice shelves shown by hachured lines.

(Singleton 1980a, 1980b) probably also are correlative. The base of the Mount Poster and Latady Formations is not exposed except perhaps in the west-central Black Coast, where it is an unconformity developed on a high-grade metamorphic complex of uncertain age (Singleton 1980a). Nor are the upper contacts of the formations exposed, except perhaps where sparse Tertiary volcanic rocks occur (Laudon et al. 1969; Singleton 1980b). Thus, the maximum thickness of the Mount Poster Formation is not known, but it probably exceeds 2 kilometers.

Where exposed, the Mount Poster Formation intertongues eastward and southward with, and then passes into, the laterally equivalent Latady Formation. On the axis of the magmatic arc, where volcanic rocks dominate, and on the flank of the arc, where volcanic rocks intertongue with the Latady, most rocks were deposited subaerially or in streams or lakes. To the south and east of the arc, however, the sedimentary rocks of the Latady Formation are marine, and they define a back-arc basin.

Most parts of the Latady Formation are probably of Late Jurassic age, judging from invertebrate fossils (Crame 1981; Quilty 1970, 1977, 1982, in press; Stevens 1967; Thomson 1980, 1982a). Some parts of the Latady in eastern Ellsworth Land, however, are Middle Jurassic (Quilty 1970, 1972, 1982, in press; Thomson 1982a). Because of its intertonguing relationship with the Latady Formation, the Mount Poster Formation also is considered to be of Late Jurassic and, at least locally, Middle Jurassic ages. The upper part of the Mount Poster Formation is not bracketed by younger or contemporaneous rocks, however, and could be as young as Early Cretaceous.

The Mount Poster and Latady Formations were intensely folded and locally thrust-faulted during latest Jurassic and Early Cretaceous time, then intruded by plutons during Early Cretaceous time.

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Geological observation of the recently discovered marine Tertiary sequence at Cape Melville, King George Island

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During the 1980–81 austral summer, a Polish field party to the northern part of King George Island, led by K. Birkenmajor, discovered an important sequence of Tertiary marine rocks at Cape Melville. This sequence at Cape Melville represents the only known occurrence of marine rocks of that age on the west side of the Antarctic Peninsula. This brief note is based on observations made during a short visit to the cape on the way to Seymour Island. Dr. Birkenmajor and members of his party currently are preparing a series of reports based on the extensive collections taken during the 1980–81 season.

Prior to the discovery of the sequence by Birkenmajor's party, the existence of marine rocks of possible Tertiary age in the vicinity of Cape Melville had been suspected, but the extent of the deposits was unknown. Knowledge of the Tertiary deposit's existence was based on several small samples of sandstones collected by the British Antarctic Survey, one of which had a mold of bivalve (Thomson, personal communication). Previous field parties in the Cape Melville region had mapped the peninsula as volcanic.

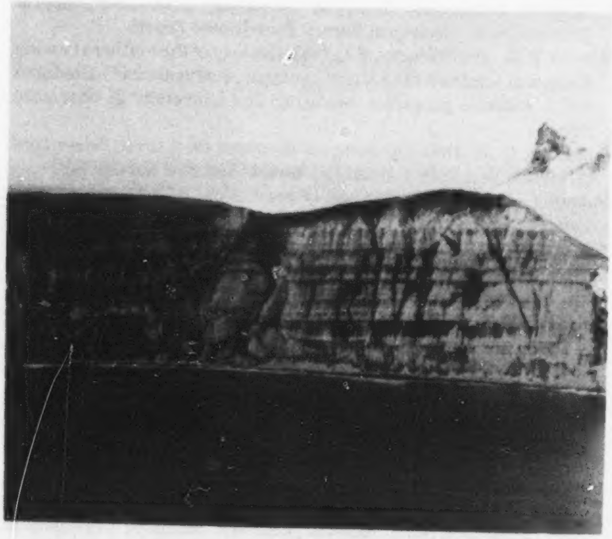

Figure 1. Northwest side of Cape Melville. The massively bedded nature of the Tertiary marine sequence is clearly visible on the cliff face.

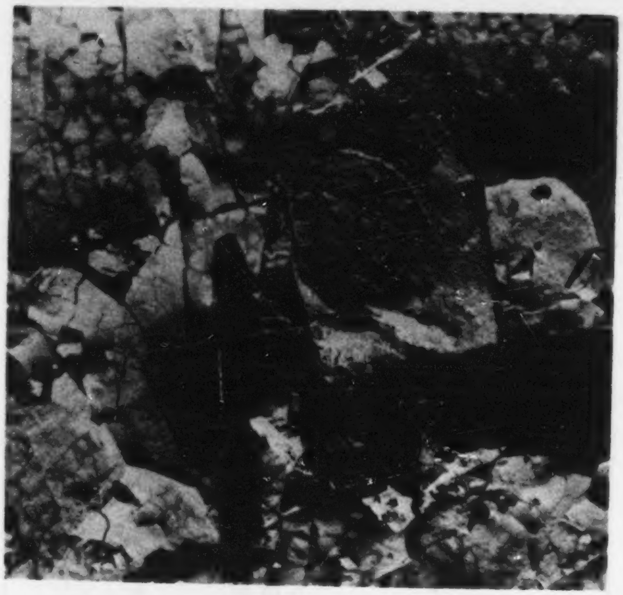

Figure 2. Drop stone (DS) in fine-grained arkosic sandstone bed exposed at the top of a seacliff on the northwest side of the cape.

Cape Melville consists of a long, narrow, flat-topped peninsula about 4 kilometers in length (figure 1). The Tertiary deposits are represented by approximately 200 meters of medium-to-dark brown sandstones unconformably overlaying massive basalt flows. The sequences are nearly flat, but there is some broad gentle warping. Because of the warping and changes in the height of the cliffs, nearly the entire section is exposed along the top of the peninsula. Numerous small dikes and minor faults cut the sequence. The sediments vary from fine- to coarse-grained, poorly sorted arkosic sandstone with occasional drop stones (figure 2), some reaching a diameter of 2 meters. Molluscs, corals, and crabs are locally abundant throughout the section. The bivalve *Malletia* is particularly common and appears to be very similar to a middle Tertiary *Malletia* common in Patagonia and central Chile. Of particular interest is the occasional occurrence of belemnite phragmocones. The presence of this Cretaceous group of molluscs with middle Tertiary molluscs and glacial drop stones suggests that the belemnites represent reworking of nearby but as yet unidentified Cretaceous deposits. The fauna from Cape Melville will provide important data about the biogeographic history of the southern circum-Pacific and climatic changes during the middle Tertiary.

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Cretaceous-Tertiary geology and paleontology of Cockburn Island

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We visited Cockburn Island by helicopter on 9 March 1982. The major purposes of our visit were to locate *in situ* outcrops of the Pecten Conglomerate and to sample for both macro- and microfaunas. Cockburn Island has a striking cone-shaped profile (figure 1). The island is nearly circular, is extremely steep-sided, and has a broad, flat surface. It is approximatey 2 to 3 kilometers across at the widest point. A prominent conical hill is located along the northwestern edge. Both this hill (about 450 meters) and the broad meseta (about 250 meters) surrounding it consist of volcanic James Ross Volcanic Group rocks. The island's distinctive physiographic form is the result of a resistant protective cap of basalt overlying the loosely consolidated Cretaceous sediments.

The stratigraphy of the island consists of three groups of rocks: Cretaceous-(?) Early Paleogene sediments exposed on the lower slopes of the island, overlain by cliff and meseta-forming James Ross Volcanic Group rocks, with Pecten Conglomerate overlying the volcanic rocks.

The Upper Cretaceous strata on Cockburn Island have not been studied in any detail. The sequence consists of approximately 200 meters of light- to medium-brown sandstones and silty sandstone with occasional concretionary horizons. The stratigraphic relationships of the Upper Cretaceous sediments on Cockburn Island are not known but are believed to be part of the Lopez de Bertodano Formation which crops out on the southern two-thirds of Seymour Island.

The basalts that cap the top of Cockburn Island (the James Ross Volcanic Group) consist of a number of horizontal flows. The total thickness is not known but must exceed 100 meters. An unexpected discovery was that the surface underneath the basalt represents an old erosional surface with moderate relief. On the northern end of the island near the penguin rookery, a moderately deep channel-like depression has been filled with basalt (figure 2). This subaerial erosion surface indicates the possible existence of vertebrate-bearing terrestrial deposits. We collected a sample of basalt for dating from the area immediately below the Pecten Conglomerate on the eastern side of the island. The James Ross Island Volcanic Group is dated as Miocene by Bibby (1966) and other workers. Rex (1976) provides whole-rock potassium-argon (K/Ar) dates for eight related basalt samples from James Ross Island and reports a range of late Miocene (6.5 million years) to late Pliocene (2.1 million years). Rinaldi and others (1978) report a whole-rock K/Ar date of 6.8 million years (late Miocene) for a dike on Seymour Island. If the volcanic sequence on Cockburn Island is closely related to those on James Ross and Seymour Islands, the Pecten Conglomerate can be no older than about 6 million years.

The Pecten Conglomerate was discovered by the Swedish South Polar Expedition. Andersson (1906) visited Cockburn Island in October 1903. He noted blocks of fossiliferous conglomerate scattered on talus slopes up to 160 meters on the eastern side of the island (Anderson 1906, p. 41, figure 3). His companion on the visit, G. Bodman, climbed to the top of the meseta from the western side and found fragments of pectens on the meseta, but none of it *in situ*. Andersson commented, "Evidently it covers only a very small part of the plateau, as blocks of the conglomerate are met with nowhere in the slopes of the island, except at locality 12" (p. 51, figure 7).

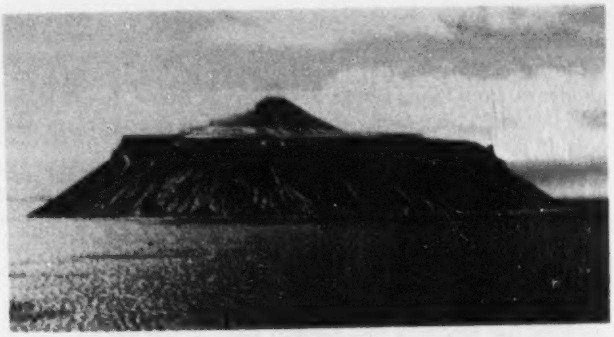

Figure 1. Southeast side of Cockburn Island. Photograph taken from Bodman Point on Seymour Island.

Except for an occasional poorly preserved bivalve, brachiopod, barnacle, and bryozoan, the macrofauna is composed exclusively of the large pecten *Myochlamys anderssoni Hennig* (Hennig 1911). Holland (1916) reported a calcareous benthic assemblage of foraminifera totaling 11 species. Andersson correlated the macrofauna with pecten-bearing Pliocene sediments at Cape Fairweather and Patagonia. Hennig (1911) believed that the macrofauna pointed to warmer conditions than found at this latitude today and concluded that the deposit belonged to a Pleistocene interglacial period. Fairbridge (1952) repeated this interpretation and suggested that deposition occurred during a period when sea level was high. Stewart (1937) examined samples from Cockburn Island and noted that the conglomerate contained common basaltic material and a few crystalline fragments. Adie (1964) included the Cockburn Island locality in his sea-level studies of the Scotia Arc and Graham

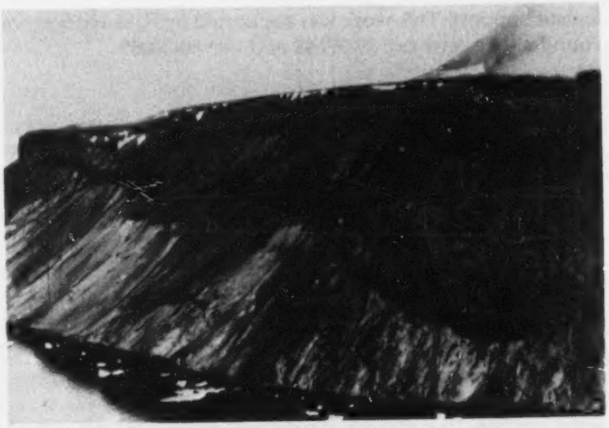

Figure 2. Contact between the Upper Cretaceous Marambio Group (light-colored rocks) and the basalt flows of the James Ross Island volcanics. Note irregular erosional surface underlying the basalts.

Land, referring to the deposit as being located on a wave-cut platform at 220–250 meters.

Barton (1965) described a correlative of the Pecten Conglomerate from Lions Rump, King George Island, South Shetland Islands. This 9-meter-thick fossiliferous deposit crops out only 45 meters above sea level.

Although the Cockburn Island fauna and the geological setting of the Pecten Conglomerate have been cited and correlated with similar pecten facies elsewhere in Antarctica (for example, McMurdo Sound—Speden 1962; Wright Valley—Turner 1967, and Webb 1974; Heard Island—Fleming 1957), very little data on the Cockburn Island deposit are available.

Along the southern and eastern sides of the meseta top, a prominent bench has been cut into the basalts (figure 3, top). It is along this bench that the Pecten Conglomerate was deposited. Although we found exposures of the conglomerate only at the extreme south and east corners of the bench, we believe the deposit covers the entire surface of the bench. Its apparent absence is the result of being covered by the downslope transport of basaltic debris by solifluction.

The exposure at the northeast corner of the bench reveals a partial section through the deposit and the stratigraphic relationships of the conglomerate with the underlying basalts. The basal sediment of the Pecten Conglomerate consists of a coarse-grained, poorly sorted, finely bedded, conglomeratic sandstone (figure 3, bottom). The clasts in the conglomerate range in size from poorly rounded pebbles to boulders and are of basaltic composition. The absence of exotic ice-rafted erratics suggests that during the deposition of the Pecten Conglomerate, this part of the Antarctic Peninsula may have been free of ice. At other nearby outcrops, the coarse conglomeratic facies is replaced by a finer grained, orange-brown gravelly sandstone with many well-preserved pecten shells. Although pectens occasionally are encountered in the coarser facies, they are most abundant in the gravelly sandstones.

The surface of the meseta is covered by coarse basaltic boulders. During our stay on the island, we observed only three or four fist-sized nonbasaltic erratics on the surface of the meseta. This near-total absence of erratics derived from the varied rock types of the Antarctic Peninsula is in marked contrast to the diverse assemblage of erratics found in the glacial debris on the meseta on nearby Seymour Island.

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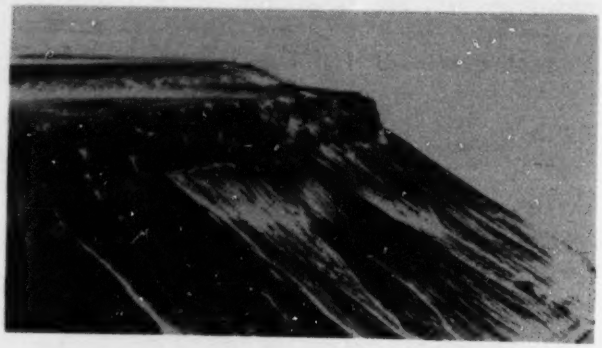

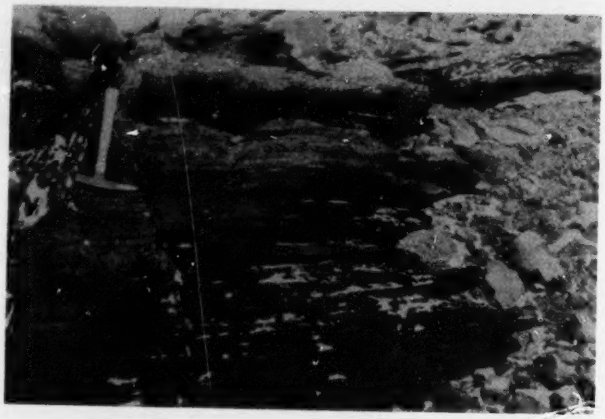

Figure 3. Top: Erosional bench along the southeast edge of the top of the meseta. Bottom: Finely laminated gravelly to pebbly sandstones of the basal part of the Pecten Conglomerate (photograph taken at the extreme northeast corner of the bench).

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Tectonics of the Scotia Arc region

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During December 1981 and January 1982, two aspects of Scotia Arc tectonics were investigated in three locations in the field: (1) the age of the metamorphic complex of the South Shetland Islands, Elephant Island (61°S 55° W) and (2) the development of the Magallanes Basin (foredeep) of the southernmost Andes in southern Chile and in southern Argentina.

Chert was collected from the northern coast of Elephant Island in a zone of low-grade (high pressure/temperature) metamorphism. It is hoped that this collection will allow paleontologic (radiolarian) determination of the age of some of the rocks in this important zone of subduction. The field relations do not offer any clues as to the age of the complex, and it is in a location where subduction may have occurred any time between the late Paleozoic and the Cenozoic (Dalziel 1982). Radiolarians from a small outcrop of chert in the South Orkney Islands have permitted the first paleontologic dating of the so-called "basement" complex in those islands (Dalziel et al. 1981). At the time this article was written, laboratory work on the material from Elephant Island had just begun.

Field study of a traverse across the foothills of the Andes at approximately 51°S latitude in Chile was completed by Terry Wilson. In addition to providing the first detailed study of the Lower Cretaceous rocks along the edge of the Andean Cordillera in the type locality of the Zapata and Punta Barrosa Formations, the work completes a section through the entire Andean range at that locality and allows comparison with the area around the Patagonian orocline to the south (see Nelson, Dalziel, and Milnes 1980; Winslow 1982).

Together with Margaret Winslow and Anne Grunow, I made a traverse along the Atlantic coast of Tierra del Fuego from Rio Grande to Cabo San Vicente. This completed (with one small gap) a section from South Georgia and Isla de los Estados in the south to the Atlantic lowlands. We collected material to improve biostratigraphic control in this poorly known area. Surprising findings were the weakness of the deformation compared with the area around 51°S discussed previously, and the fact that the strike of the inclined Upper Cretaceous strata along the Atlantic coast of easternmost Tierra del Fuego is northwesterly rather than easterly. In this it mimics the structure at Puerto San Juan at the eastern tip of Isla de los Estados (Dalziel and Palmer 1979).

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Trace element chemistry of mineralized rocks, Livingston Island (South Shetlands), Gerlache Strait, and southern Anvers Island

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Composite rock-chip samples collected during cruise 81-3 of R/V *Hero* (Pride, Moody, and Rosen 1981) have been analyzed quantitatively for copper, molybdenum, lead, zinc, gold, silver, tungsten, and fluorine. A total of 124 samples was collected from the South Bay and False Bay areas of Livingston Island, from islands and along the mainland coast of the Gerlache Strait, and from islands and along the coast of southern Anvers Island from Arthur Harbor to Cape Monaco (figure). Each composite sample consisted of 10 to 20 small rock chips, collected specifically to provide representative samples of the mineralized and altered rocks. Unmineralized material also was collected from several of the localities. With few execptions, the mineralization and alteration is fracture-controlled and occurs as veins. Representative hand specimens also were collected at each sample station, and these now are being studied in thin section and by polished surface microscopy.

The table summarizes the chemical data from the composite samples. Mean element abundances and the ranges in concentrations are given for the localities visited during cruise 81–3.

The elements studied typically are present within mineralized systems that contain porphyry-type copper and molybdenum. Lead, zinc, gold, and silver commonly are present in veins peripheral to porphyry copper and molybdenum mineralization. Fluorine and, sometimes, tungsten occur with porphyry molybdenum mineralization.

Anomalous concentrations of copper, lead, zinc, silver, and perhaps gold are present in two areas: (1) the eastern Gerlache Strait area, along the coast north of Bahia Frei (Recess Cove), at Eckener Point and Pelseneer Island, and at the point designated "Marc?" by Alarcón and others (1976); and (2) along the east shore of South Bay, Livingston Island. The mineralization in the eastern Gerlache Strait is of greatest interest. Anomalous copper-molybdenum-tungsten, probably representing a higher temperature hydrothermal environment, was found also at two localities: (1) in the Arthur Harbor area (Palmer Station vicinity, Norsel Point, and the immediate offshore islands); and (2) along the northeast shore of False Bay, Livingston Island.

Anomalous gold (averaging nearly 200 parts per billion for 24 samples) is present within the vein system that carries the anomalous molybdenum in the vicinity of Palmer Station, southern Anvers Island. Lower concentrations of gold (11–33 parts per billion) also were found in rocks from the east South Bay area, Livingston Island, and from Pelseneer Island and the point designated "Marc?" in the Gerlache Strait.

Molybdenum is an important component of porphyry copper mineralization in Chile, and it is conspicuous (as molybdenite) in rocks of the peninsula region. Investigations by Cox, Ciocanelea, and Pride (1980) and by Pride and others (1981) have noted molybdenite along joint surfaces and within veins in rocks from Palmer Station and from the northeastern False Bay

Mean element concentrations, Livingston Island, Gerlache Strait, and southern Anvers Island

Location	Number of samples	Copper (ppm)[a]	Molybdenum (ppm)	Lead (ppm)	Zinc (ppm)	Gold (ppb)[b]	Silver (ppm)	Tungsten (ppm)	Fluorine (ppm)
Livingston Island									
South Bay	37	673	0	1,550	1,081	33.1	4.6	0.1	244
		(0–6,371)[c]	—	(8–15,114)	(78–13,174)	(0–570)	(0–10)	(0–4)	(40–617)
East False Bay	10	3,534	57.4	10.5	50.7	14	2.7	3.8	269
		(14–10,803)	(0–561)	(2–25)	(1–114)	(1–50)	(0–4)	(0–16.8)	(40–427)
Gerlache Strait		23.5	0.03	309	102	4	56.2	1	425
Eckener Point	4	(14–36)	(0–1)	(10–1,173)	(36–140)	(2–6)	(3–152)	(0–4)	(203–650)
Coast north of Bahia Frei (Recess Cove)	2	450	0	44,660	14,556	7	24.5	0	558
		(160–740)	—	(40–89,292)	(84–29,027)	(3.5–9)	(5–44)	—	(292–824)
Andrée Island	4	7	0	22	54.5	10	4	2	249
		(0–28)	—	(11–36)	(25–140)	(4–25)	(3–5.5)	(0.4)	(110–568)
Marc(?)[d]	4	6	0	11.5	75	11	2.8	3.1	272
		(0–8)	—	(8–16)	(42–97)	(4–17)	(2–3)	(0–8.4)	(122–487)
Pelseneer Island	8	12.7	1.3	12.6	48.3	24	23.1	1	110
		(0–70)	(1–2)	(2–25)	(18–96)	(0–180)	(1–160)	(0–4)	(40–385)
Thompson Peninsula (Anvers Island)	2	36	0	17	105	3.5	4	2	237
		(18–54)	—	(12–22)	(98–112)	(3.4)	—[e]	(0–4)	(213–261)
Southern Anvers Island									
Palmer Station vicinity and Bonaparte Pt.	24	1,173	44	370	109	198	23.7	3.7	336
		(0–8,553)	(0–615)	(6–7,096)	(2–732)	(2–3,100)	(0–230)	(0–39.3)	(40–1,257)
Norsel Point	7	157	0.2	13.4	78.7	12	3.9	2.5	144
		(0–797)	(0–1)	(8–18)	(32–182)	(3–30)	(2–5)	(0–5.6)	(40–280)
Offshore islands (Arthur Harbor)	15	49.2	0.1	225	73.7	6	8.6	0.3	202
		(0–370)	(0–1)	(6–3,154)	(24–142)	(0–40)	(2–67)	(0–4)	(89–452)
Cape Monaco and Gossler Islands	5	4.8	0	16	47	2.7	11.6	0	270
		(0–14)	—	(10–22)	(37–57)	(2–3.5)	(2–48)	—	(205–392)
Joubin Islands	2	0	1.4	9,684	40	4	72	2	77
		—	(0–2.8)	(8–19,360)	(38–42)	—[e]	(8–135)	(0–4)	(40–114)

[a] ppm = parts per million.

[b] ppb = parts per billion.

[c] Numbers in parentheses indicate range in concentrations from which the mean was calculated.

[d] Point designated "Marc?" in Alarcón and others (1976).

[e] Concentration of both samples was 4.

area. In fact, molybdenite is more conspicuous in outcrop than are the copper sulfides that typify porphyry copper mineralization. Molybdenum may dominate the porphyry mineralization, if such mineralization exists in this part of the peninsula.

Anomalous tungsten is also present in samples from the Palmer Station and northeast False Bay areas (table). Fluorine exhibits no distinctly positive correlation either with molybdenum or with tungsten.

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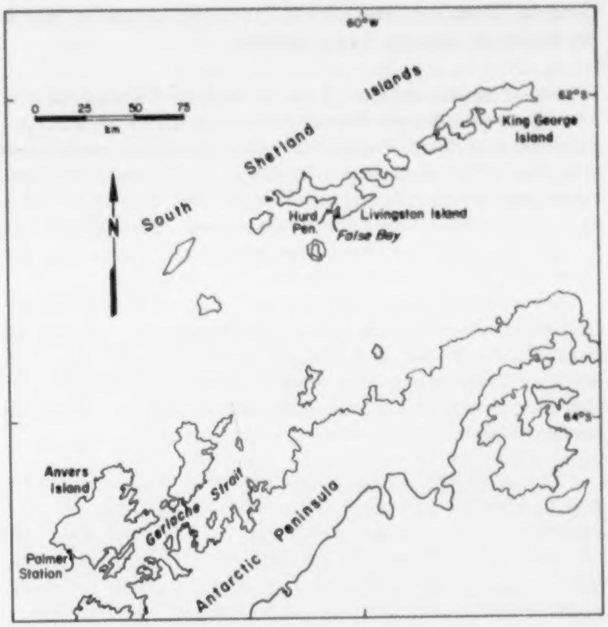

Location map for the northern Antarctic Peninsula.

Conchostracan dispersal (Paleozoic/Mesozoic) between South America, Africa, and Antarctica

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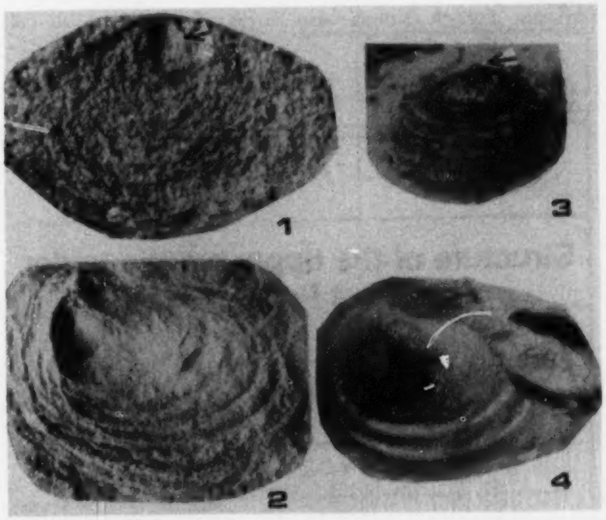
This is a progress report from my monograph on Gondwana conchostracans which is in preparation.

Brazil, Gabon, and Angola. Previously, I reported (Tasch 1979) the first notice of the occurrence of the Gabon genus *Gabonestheria* (photograph 2 in the figure) in the lower part of the Rio do Rasto Formaton (Upper Permian) at São Pascoal, Brazil. I am now reporting that a new species of genus *Cornia* (1 in figure) has been found in samples from the same site.

Species of both these genera also occur in the Karoo "Phyllopod Beds," Upper Cassanje Series, Northern Angola, and are Lower Triassic in age (Oesterlen Collection, 3 and 4 in figure). These new data on the spread of *both* the nonmarine gabonestherid and corniid genetic bioprogram from Lower Permian (Gabon) to Upper Permian (Brazil) to Lower Triassic



Conchostrachan specimens: (1) *Cornia* n.sp. (Tasch collection—TC 90069), Rio do Rasto Formation, São Pascoal, Brazil, Upper Permian. Bed 1A. Length, 4.4 millimeters. Arrow points to umbonal node. (2) *Gabonestheria* n.sp. (TC 65000), same locality as (1), Bed 3. Length, 2.5 millimeters. Umbonal area crushed. (3) *Cornia* n.sp. (TC 90004), Karoo "Phyllopod Beds," Upper Cassanje Series between Quela and Xandel, Northern Angola, Upper Triassic. Length, 2.5 millimeters. Arrow points to umbonal node. (4) *Gabonestheria gabonensis* (Marlière 1950) (TC 90009), same beds and series as (3), between Xandel and Muteba, Northern Angola. Length, 2.4 millimeters. Umbonal area crushed.

(Angola) (Tasch and Oesterlen 1977) strengthen fossil evidence for the South America-Africa ligature.

Blizzard Heights and Zaire. I have assigned a Blizzard Heights (BH) (Queen Alexandra Range, Antarctica) conchostracan species (Tasch station 1, bed 4) to *Cyzicus (Lioestheria) malangensis* (Marlière 1950), as emended by Defretin Le-Franc (1967) and reassigned by me. Defretin Le-Franc's (1967) Zaire specimens were bracketed as Late Triassic-Jurassic age. The basis for this assignment is the overlap of parameters and ratios with the Zaire data, as well as valve features.

Here is a new indication of dispersal of a cyziciid bioprogram, between Africa and Antarctica. Taken in conjunction with the Brazil-Gabon-Angola connection, a spread of conchostracan bioprograms between these three southern continents is a further clue to active nonmarine dispersal during late Paleozoic/Mesozoic time.

Africa. Eighteen African countries have yielded Paleozoic and/or Mesozoic fossil conchostracans. The greatest concentration of fossiliferous sites is below the Equator. Zaire has the most sites, followed by the Republic of South Africa, Angola, Zambia, and Zimbabwe. North of the Equator, Gabon, Niger, Algeria, and Morocco each have several sites. Many genera have been reassigned, and species newly described. Twelve conchostracan genera are recognized in the monograph: *Cyzicus, Paleolimnadia, Gabonestheria, Cornia, Estheriina, Asmussia, Leaia, Afrolimnadia* n.g., *Glyptoasmussia, Paleolimnadiopsis, Echinestheria,* and *Estheriella.* Intercontinental faunal relationships are clarified as older taxonomy is corrected and new species discovered.

South America. Reports of fossil conchostracan-bearing sites are lacking for only four South American countries: Ecuador, Surinam, French Guiana, and Paraguay. An Argentine colleague has notified me recently of the first Uruguay find. The greatest density of conchostracan sites, as in Africa, is below the Equator. Brazil has the greatest number of such sites, ranging from Permian through Mesozoic. Argentina (Permo-Triassic) and Chile (Triassic) have a few sites each. Above the Equator, Colombia and Venezuela (Jurassic/Cretaceous) have yielded some new forms, now in my collection.

After reassignments of genera, the South American fossil conchostracans from nine countries included the following 17 genera recognized in the monograph: *Cyzicus, Leaia, Estheriina, Paleolimnadiopsis, Graptoesthiella, Aculestheria, Cornia, Gabonestheria, Acantholeaia, Unicarinatus, Monoleaia, Macrolimnadiopsis, Pseudoasmussia, Asmussia, Pseudoasmussiata* (Defretin Le-Franc 1969), *Cyclestheroides,* and *Echinestheria.* It will be obvious, comparing the fossil conchostracans from both continents, that many of the same genera occur. These relationships will be further explored and extended to the other Gondwana continents.

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Structure of the upper mantle under the East Pacific Rise

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The global great circle that includes the epicenter of the Gazli, Uzbekistan, earthquake of 17 May 1976 ($M_s = 7.2$), Los Angeles, and the South Pole lies remarkably close to the East Pacific Rise over much of the length of the rise. The earthquake excited fundamental mode surface waves with measurable periods as long as 400 seconds and was strong enough that Rayleigh wave trains R1, . . .R6 were recorded on the ultralong-period seismometers operated at both the South Pole and at UCLA; our convention is that R*n* identifies the *n*th pass of globe-circling Rayleigh waves past the station. With so many passes of Rayleigh wave trains in both directions at both stations, we have a unique opportunity to measure phase differences of Rayleigh waves over a path 85 percent of whose length between the two stations lies along the East Pacific Rise. Since the dispersion of surface waves is influenced by the distribution of inhomogeneities in the Earth's interior, we have used the measured dispersion at the two stations to determine the structure of the upper mantle to a depth of 450 kilometers under the rise (Wielandt and Knopoff 1982).

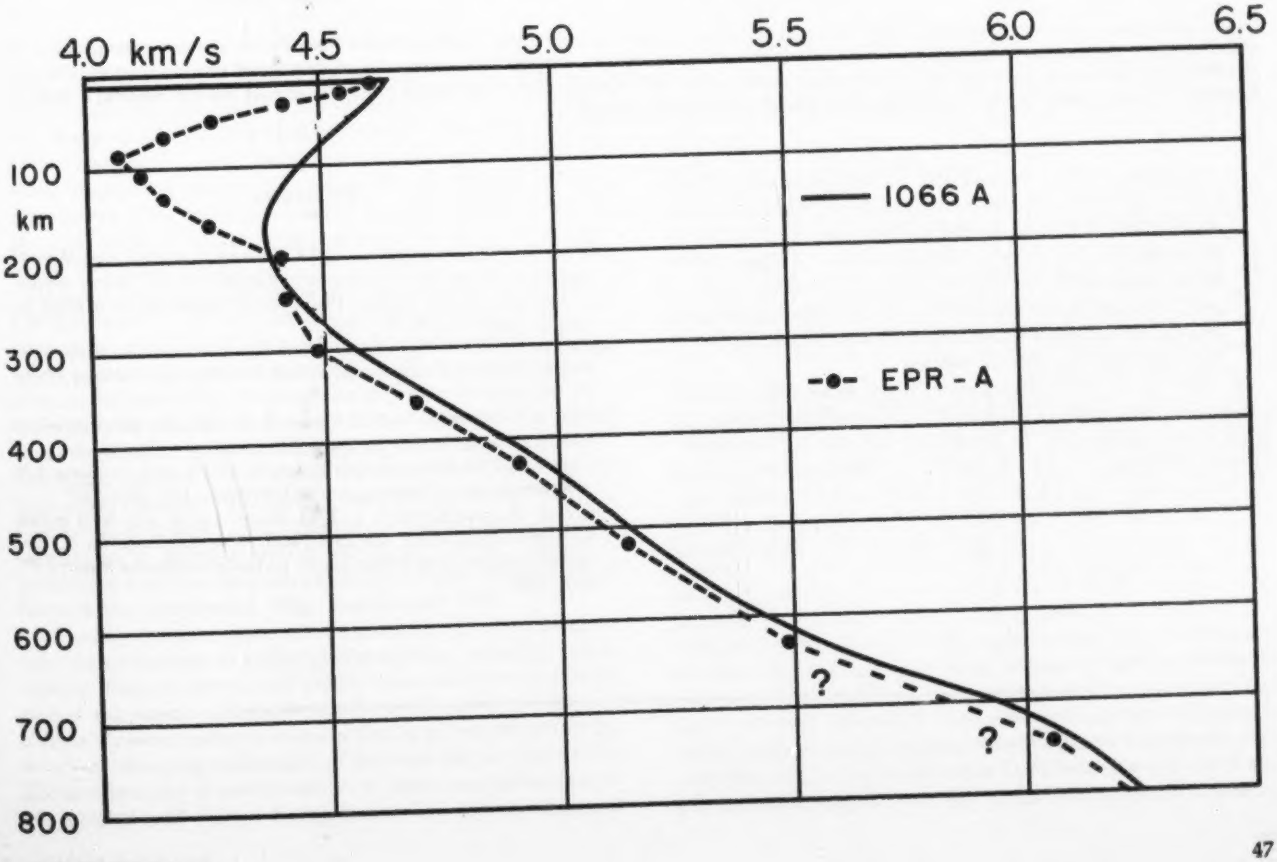
After windowing, filtering, and harmonic analysis of the two seismograms, differential phase delays were constructed for the three pairs of traverses (i.e., both directions) of the path between the stations. The scatter among the phase delays was small over the period range 40 to 400 seconds. Corrections to the average of these values were made for the part of the path that crosses West Antarctica and for the phase shift due to the wave propagation through the epicentral antipodal point. In the latter regard, the antipodal point to the earthquake is roughly midway between the two stations; Rayleigh waves converging on and diverging from the antipodal point give apparent phase delays different from those one might expect from a source and antipodal point outside the station pair. The corrections map any circular wavefront on the surface of a spherical model Earth into a linear wavefront on the surface of a plane model Earth The corrections we use have been given by Wielandt (1980).

We apply a linear inverse procedure to derive the mantle structure; we use a formulation given by Jackson (1979). The result of the inversion depends on the parameters of the starting models, for example, whether or not jump discontinuities in physical properties in the Earth's interior are included and whether or not other geophysical constraints such as thermodynamic data for silicate minerals are taken into account. We used three starting models: Gilbert and Dziewonski's (1975) global average Earth models 1066A and 1066B and a thermodynamically constrained variant of 1066B. We call the three final models EPR-A, -B, and -C, respectively (figures 1 and 2).

The results are as follows:

- We find that the S-wave (shear wave) velocities under the East Pacific Rise are lower than the global average down to a depth of about 200 kilometers, with a minimum of 4.1 kilometers per second at a depth of around 100 kilometers. Although these velocities are low with respect to the global average in this depth range and also low with respect to continental values, they are not much different from the values proposed for the low-velocity channel for the entire Pacific Basin (Leeds, Knopoff, and Kausel 1974).
- The S-wave velocities between 200 and 400 kilometers depth are less than the global average by a very small amount, on the order of 0.05 kilometers per second, and may even be the same as the global average in this depth range.
- If the olivine-spinel phase transformation, usually identified to be at a depth of about 440 kilometers, is included as a parameter, it is depressed by about 50 kilometers if there are no deeper thermal anomalies (model EPR-B). From the Clapeyron slope for this phase transformation, this depression means that mantle temperatures in this depth range are elevated relative to the global average Earth. If the phase transformation is not included as a parameter, the inversion yields reduced S-wave velocities near these depths that are reduced correspondingly.
- We can make no definitive assertions regarding deeper anomalies. Models EPR-A and -C, with thermal anomalies that extend down to the core, are consistent with the

Figure 1. S-wave (shear-wave) velocity in the upper mantle as a function of depth under the East Pacific Rise. The perturbation of global average reference model 1066A is unconstrained at the bottom. The EPR result shows a large velocity anomaly in the upper mantle and a small but significant velocity anomaly to very great depths.



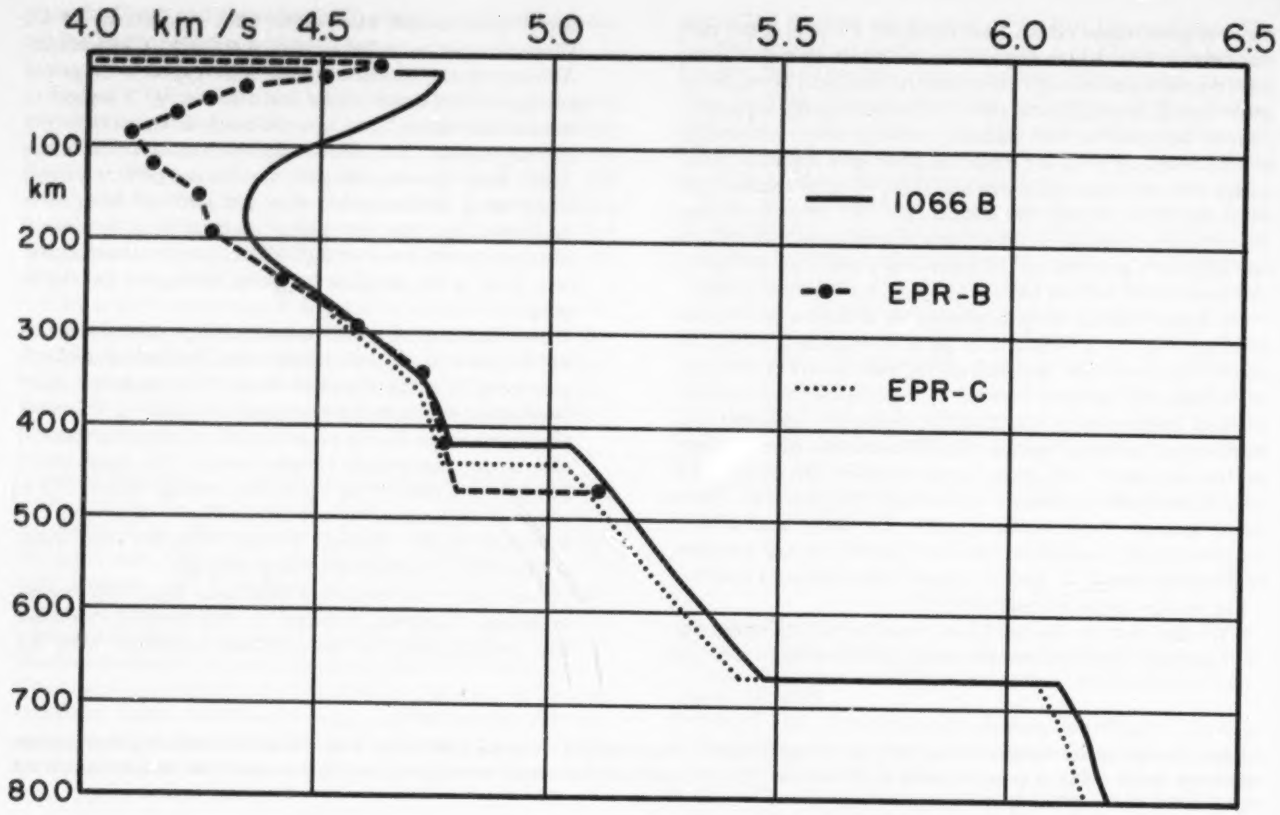


Figure 2. S-wave (shear-wave) velocity in the upper mantle as a function of depth under the East Pacific Rise. The model EPR-B perturbation of global average reference model 1066B is constrained so that no anomalies are permitted below the olivine-spinel transformation, which is significantly depressed under the EPR. Model EPR-C perturbation of 1066B fixes the temperature gradients across the transitions; a velocity anomaly corresponding to high temperatures is found to very great depths.

observations; other models with thermal anomalies down only to the olivine-spinel transformation at 450 kilometers (model EPR-B) and no deeper are also consistent with the observations. The velocity anomalies are consistent with the assumption that an elevated temperature of the order of 140°C is found in the region between 200 kilometers depth and the spinel-oxide transition at 671 kilometers. The thermal anomaly may extend deeper.

In view of our third conclusion, anomalous temperatures consistent with convective upwelling are observed to depths as great as 450 kilometers. To determine whether the anomalies indeed extend deeper, we will have to wait for an earthquake on the South Pole-UCLA great circle having either a richer long-period excitation spectrum than the Gazli earthquake, which cut off at periods of about 400 seconds, or a better source spectrum of higher modes.

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Glacial geology

Late Quaternary geology of the Rennick Glacier area, northern Victoria Land

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As part of the Northern Victoria Land Project (NVLP) in 1981–82, we mapped glacial erosional and depositional features near Rennick Glacier. Our primary objective was to relate local glacial history to overall fluctuations of the east antarctic ice sheet, particularly during late Wisconsin and Holocene times. The results allow refinement of the antarctic ice-sheet reconstruction used in CLIMAP modeling experiments of the glacial world 18,000 years ago (CLIMAP 1976; Stuiver et al. 1981).

Rennick Glacier, an enormous valley glacier, flows from south (73°30′S) to north (73°18′S) for 400 kilometers along the western edge of the northern Victoria Land mountains (162°30′E), effectively separating the east antarctic ice sheet from the Evans Névé in the mountains. Rennick Glacier drains local cirques and intermontane catchment basins, western Evans Névé, and a dome at the eastern end of a topographic ice ridge that extends outward from central East Antarctica to northern Victoria Land (Canadian Hydrographic Service 1980; Levanon 1982). Rennick Glacier heads in mountain cirques at 2,400 meters elevation and terminates in Rennick Bay in the Pacific Ocean. Today the grounding line is located more than 120 kilometers inland from Rennick Bay (Mayewski, Attig, and Drewry 1979).

Mountain ranges adjacent to Rennick Glacier commonly exhibit classic features of alpine glacier erosion, including glacial valleys, cirques, horns, and arêtes. Many adjacent mountain ranges are heavily glaciated and feed tributaries to Rennick Glacier. However, other mountains that lie in the path of katabatic winds sweeping northward off the ice sheet are less heavily glaciated because of wind ablation; in these mountains numerous cirques and valleys facing downwind are now ice free except where they are partly backfilled by Rennick ice tongues. Such cirques and valleys must predate the present ice-and-wind regime.

A conspicuous glacial trimline is superimposed on these alpine erosional features along Rennick Glacier. This trimline rises systematically inland from 1,000 meters elevation near Rennick Bay to 2,800 meters at the head of Rennick Glacier in the Mesa Range and more than 2,800 meters in the Outback Nunataks at the present eastern tip of the east antarctic ice ridge and local dome. This trimline, which crosses numerous bedrock lithologies, separates two altitudinally defined landscape types. In most bedrock lithologies, mountain ridges and crests above the trimline are serrated with rock pinnacles produced by physical weathering. Only granite, Beacon Supergroup sedimentary rocks, and Ferrar Dolerite in the middle reaches of the glacier fail to show serrations above the trimline. Rather, they exhibit deep grüssification, spalled surfaces, tors, or severely frost-shattered bedrock. With the exception of several sites in the Morozumi Range, we did not find erratics above the trimline; nor did we locate striated and polished bedrock surfaces. Below the trimline, bedrock crests and ridges, as well as ice-free valleys, show erratics, drift patches, and moraines near blue-ice areas. Moreover, glacial striations, polish, and grooves are widely preserved on bedrock surfaces that were overrun by wet-based ice and that have not undergone rapid postglacial grüssification or frost-shattering.

Extensive patches of drift, including a few moraines, occur below the trimline in ice-free areas and are particularly widespread on the west side of Rennick Glacier in the Lichen Hills, the Morozumi Range, and the Helliwell Hills. We studied soil development and surface-boulder weathering of this drift at 11 sites. Tables 1 and 2 show surface-boulder weathering and soil morphology in drift. Complete chemical analyses are in progress. The available soil data taken, in conjunction with geologic mapping, suggest a twofold division of the drift. The older drift occurs as patches that extend in elevation from the trimline down to within several meters of the present Rennick Glacier. This drift, which is unbroken by moraines except in the Morozumi Range, shows minimal soil development. The solum averages 3 centimeters in thickness. Although the solum is cohesive, the underlying regolith readily collapses into the pit during excavation. Salts are not visible in these soils except as encrustations beneath clasts. These soils show a poorly developed desert pavement. Although boulders on both the older drift and the younger drift (to be discussed later) are striated, twice as many boulders on the younger drift are striated compared with the older drift. The older drift contains 20 percent fewer boulders and 49 percent more boulders with desert varnish than the younger drift (table 1). Soils on the older drift are similar in development to those of the Triology end moraine in eastern Wright Valley (Bockheim 1978, 1979), the Ross Sea drift in eastern Taylor Valley (Bockheim 1977), and the Britannia drift of the Darwin Glacier area (Bockheim and Wilson 1979).

The younger drift in northern Victoria Land forms a fresh, ice-cored moraine adjacent to blue-ice areas of Rennick Glacier and many small local glaciers. These moraines are characterized by striated, unweathered boulders on coarse grūs over clean ice. Typically, these soils exhibit no horizon development and contain many polished and striated clasts within the profile. Desert pavement was not observed on this drift.

In an effort to differentiate statistically the two drifts, unpaired t tests were performed on selected soil-morphologic, soil-chemical, and surface-boulder weathering features. Depth of coherence, depth to ice-cemented permafrost, electrical conductivity of the surface horizon, and percentage of boulders with desert varnish are significantly (p 0.05) higher on the older drift, whereas percentage of striated boulders and depth to ice-core or to ice-cemented permafrost are significantly (p 0.05) higher on the younger drift (tables 1 and 2).

The trimline represents the former profile of an expanded Rennick Glacier because it rises consistently inland across several bedrock types and because it marks a sharp change in glacial surface features. On the basis of a comparison of surface-rock weathering and soil development in the older drift with radiocarbon-dated Ross Sea drift and correlative drifts further south in the Transantarctic Mountains (Bockheim 1977, 1978, 1979; Bockheim and Wilson 1979; Stuiver et al. 1981), we judge that Rennick Glacier last thickened to reach the trimline at the maximum of late Wisconsin glaciation and that it subsequently lowered to its present level in late Wisconsin and Holocene times. We have found no evidence that widespread readvances interrupted general deglaciation. The former ice-surface profile delimited by the trimline indicates that grounded ice extended onto the east antarctic continental shelf seaward of Rennick Bay. Concurrently, Evans Névé thickened 100–200 meters. The dome at the end of the east antarctic ice ridge extended farther eastward into the upper drainage area of Rennick Glacier and thickened by 600 meters near Outback Nunataks.

If our conclusions are correct, they indicate out-of-phase behavior of domes at the end of east antarctic ice ridges in northern Victoria Land (Levanon 1982) and in southern Victoria Land inland from the dry valleys (Drewry 1980). Whereas the northern Victoria Land dome thickened at the late Wisconsin maximum (presumably in response to sea-level lowering), Taylor and Wright outlet glaciers of the southern Victoria Land ridge receded (presumably in response to reduced precipitation) (Denton, Armstrong, and Stuiver 1971; Drewry 1980; Stuiver et al. 1981). While the northern dome thinned by 600 meters during late Wisconsin and Holocene time (presumably in response to sea-level rise and inland migration of the grounding line from the east antarctic continental shelf), outlet glaciers from the southern dome advanced and now, with the exception discussed below, occupy their maximum positions since late Wisconsin time (presumably in response to increased precipitation as the Ross Sea underwent deglaciation) (Denton et al. 1971; Dort 1970; Stuiver et al. 1981). Radiocarbon (carbon-14; ^{14}C) ages of 17,790 ± 70 years (QL-1257), 21,200 ± 200 years (QL-1246), and 17,530 ± 70 years (QL-1247) (Stuiver et al. 1981) date undisturbed, perched deltas originally deposited in glacial Lake Washburn but now only 10–300 meters from Taylor Glacier snout. These dates reinforce earlier conclusions from geomorphic field data (Denton et al. 1971; Stuiver et al. 1981) that Taylor Glacier now occupies its maximum position since late Wisconsin time.

The exception mentioned previously is that fresh ice-cored lateral moraines discontinuously fringe Taylor and Wright Glaciers. Similar lateral moraines fringe most alpine glaciers in the dry valleys region. These moraines have been dated by ^{14}C dating at less than 3,100 years old at two localities (Stuiver et al. 1978). We believe that a general Holocene glacier advance in the dry valleys region (due to increased precipitation) was interrupted by relatively severe climatic warming that began less than 3,100 years ago and lasted about 900 years. Increased ablation associated with this climatic warming caused ice-marginal retreat, leading to moraine formation. Subsequent cooling caused many glacier snouts to override these ice-cored moraines and occupy their maximum late Wisconsin positions. This reactivation has not yet affected most lateral margins, which are still fringed by intact ice-cored moraines.

In northern Victoria Land the fresh, ice-cored moraines of the younger drift fringe both Rennick Glacier and small, independent glaciers. Therefore, we think they record a climatic event. These ice-cored moraines are strikingly similar to their counterparts in southern Victoria Land in terms of position relative to

Table 1. Weathering of boulders on drift in northern Victoria Land

Profile	Number (per 314 sq m)	Desert varnish (%)	Pitting (%)	Spalling (%)	Fractured (%)	Ventifacted (%)	Striated (%)
Younger drift							
81-23	311	51	0	1	1	0	61
81-26	793	17	0	0	4	0	82
81-29	491	67	0	5	3	0	50
Average	532	45	0	2	3	0	64
Older drift							
81-19	290	92	4	5	2	1	45
81-20	536	82	1	2	1	0	29
81-21	181	96	5	5	7	0	9
81-22	934	78	0	5	0	0	10
81-24	505	94	1	7	9	0	23
81-25	112	86	0	4	4	0	58
Average	426	88	2	5	4	0	29

Table 2. Morphologic properties of soils in drift in northern Victoria Land

Profile	Depth oxidation (cm)	Depth of pseudomorphs (cm)	Depth of salt encrustations (cm)	Depth of slightly coherent consistence (cm)	Depth to ice cement (cm)	Depth to ice core (cm)	Electrical conductivity (ms per sq cm)
Younger drift							
81-23	0	0	0	22	—	70	0.06
81-26	0	0	0	0	—	35	0.11
81-27	0	0	0	0	—	3	0.07
81-29	0	0	0	0	—	30	0.097
81-31	0	0	0	0	—	8	—
Average	0	0	0	4	—	29	0.08
Older drift							
81-19	0	0	10	10	10	—	0.35
81-20	0	0	0	8	8	—	0.75
81-21	6	0	6	6	110+	—	0.22
81-22	0	0	0	22	22	—	0.50
81-24	11	0	11	49	100+	—	0.35
81-25	0	0	0	50	50	—	1.12
Average	3	0	5	24	50	—	0.55

ice margins, morphology, surface-rock weathering, and soil development (Bockheim 1978). Therefore, we suggest that the ice-cored moraines in both southern and northern Victoria Land record the same climatic event. If our inferences are correct, the presence of marginal ice-cored moraines as far seaward as the present grounding line suggests that Rennick Glacier reached its present level before 3,100 years ago (in carbon-14 years) and that grounding-line recession has not occurred subsequently.

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Upper Rennick Glacier ice mass fluctuation study

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Glacial geologic mapping conducted during the 1974–75 field season revealed that at least two glacial events have affected the upper Rennick Glacier region: an older Evans glaciation probably correlative with a major expansion of the east antarctic ice sheet, and the Rennick glaciation, which since the end of the late Wisconsin has been in a retreat phase (Mayewski, Attig, and Drewry 1979). Ice surface reconstructions suggest that (1) in the area of the current Rennick Glacier grounding line, approximately 120 kilometers inland from its current terminus, Evans ice was at least 1,000 meters higher and Rennick ice as much as 600 meters higher than today, and (2) the glacier's grounding line extended at least 98 kilometers, and as much as 43 kilometers, farther north during the maximum stages of these glaciations, respectively (Mayewski et al. 1979). Retreat from the maximum position held by Rennick ice continues to be characterized by inland migration of the Rennick Glacier grounding line and adjustments in the size and dynamics of local alpine glaciers (Mayewski et al. 1979), plus the lowering of lake levels and changes in the size of snow patches (Mayewski and Attig 1979).

During the 1980–81 and 1981–82 field seasons, sites used for detailed investigation were visited in order to document and understand the physically and climatically induced changes characteristic of the retreat phase of the Rennick glaciation. Since Rennick Glacier is the northernmost outlet glacier in the Transantarctic Mountains, is not obstructed by the Ross Ice Shelf, and drains into a seasonally ice-free ocean, it provides potentially an excellent example of the state of activity of east antarctic coastal ice. The investigations conducted during these seasons included: continued glacial geologic mapping; monitoring of velocity/strain/ablation on Rennick Glacier and on two alpine glaciers close to the grounding line of Rennick Glacier; radio-echo sounding at sites at which velocity/strain/ablation were monitored and in Evans Névé; and shallow ice coring (2–8 meters) at several sites to assess relatively recent (100 years) mass balances, timing of deposition, and source(s) of deposition by means of analysis of β-activity, reactive iron, reactive silicate, sodium, and chloride.

Laboratory analyses are continuing. Preliminary results of the field study indicate that the upper Rennick Glacier region is characterized by glaciodepositional and glacioerosional features characteristic of wet-based ice, surface-water flow, and ablation values far more intense than in more southerly areas of the Transantarctic Mountains, and by marked thinning of ice in Evans Névé. The latter eventually may lead to a dramatic decrease in the volume of ice entering Rennick Glacier, since Evans Névé is the main source for this glacier, and to even more intensified inland migration of the glacier's grounding line.

The 1981–82 field party—Paul A. Mayewski, William Berry Lyons, Boyd Allen, and Peter Feuerbach—was in the field from 22 November 1981 to 5 January 1982. We would like to thank the officers and enlisted men of VXE-6 for helicopter and Hercules support and the staff at the northern Victoria Land camp for assistance. This research was supported by National Science Foundation grant DPP 79-0755.

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Ross Sea glaciations: Events in Victoria Valley

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During the 1981–82 field season reexamination of Victoria Valley, previously studied by P. E. Calkin (1971), continued. The purpose of this reexamination primarily has been to determine the extent to which lower Victoria Valley was invaded by ice of the Ross Sea glaciations (Denton 1971). The field team, made up of myself, Woodrow B. Thompson, and Margaret P. Borns from the University of Maine and Sankar Chatterjee from Texas Tech University, spent 35 days in the field, concentrating on the lower and upper Victoria Valley between 26 December and 27 January.

Field observations support Calkin's (1971) suggestion that the Victoria Lower Glacier (1) at its maximum advanced westward at least as far as approximately 8 kilometers from its present terminus, to the vicinity of middle Lake Vida, and (2) during a later event terminated approximately 6 kilometers west of its present terminus. However, work south and west of Lake Vida suggests that the glacier had extended westward at least 15 kilometers from its present terminus, where its deposits are overlain by till deposited by a glacier advancing eastward from the western end of the valley.

The deposits of the former, more extensive Victoria Lower Glacier are identified primarily by an absence of clasts derived from the Beacon Group and by the presence of clasts of scoriaceous olivine basalt, presumably derived from the Ross Sea floor to the east and transported into the valley by a glacier moving inland from the sea.

A higher stand of Lake Vida was identified by the presence of lacustrine calcareous concretions up to approximately 12 meters above the level of the present lake. The age of an ice-contact delta on the eastern end of the lake places this high lake stand at approximately 10,000 years ago.

An outwash delta in Upper Victoria Valley, approximately 4 kilometers northwest of the end of the lake, also appears to be graded toward the former high lake level of Lake Vida. This outwash was traced to a former ice-margin position of the Victoria Upper Glacier approximately 8 kilometers south of the present margin. This position is marked by very "fresh" looking end moraines relative to those immediately adjacent down the valley.

It appears that this ice-margin position of the Victoria Upper Glacier was contemporaneous with that of the Victoria Lower Glacier, dated at approximately 10,000 years ago. It is expected that radiocarbon dates, to be derived from fossil algae collected from within the western delta, will confirm this tentative correlation.

The question of the source of the former, more extensive Victoria Upper Glacier, either from the inland ice or from local alpine basins, is unresolved at this time, as is the reason for the contemporaneous enlargement of Lake Vida.

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Patterned-ground studies in Victoria Land

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Patterned ground is a general term for those features variously described as polygons, circles, nets, steps, and stripes which characterize, but are not restricted to, ground subject to frost action. This study is restricted to polygons generated by thermal contraction cracking in permafrost during the annual change of the seasons. In winter, cold ground temperatures cause ice-cemented ground to shrink and develop cracks in polygonal array normal to the surface. In the cracks that outline the polygons, drifting sand in arid areas and ice in humid areas add increments of material to the ground. The process continues annually, building wedge-shaped forms whose widths reflect the rate of growth and the total time involved. Unconsolidated sand and gravel, till, and even bedrock may host the wedges. Because ice has a much higher coefficient of thermal expansion than rock, wedges that grow in fine-textured sediments cemented with much ice grow much faster than wedges in bedrock or in sediments cemented with little ice. The purpose of this study was to determine the age of polygons in various geomorphic settings. This is done by measuring annual growth rates of the wedges and dividing the average maximum width of wedges in various geomorphic settings by the mean annual growth rate. Thus, ages of young glacial deposits, drained lake beds, abandoned stream channels, and other morphologic forms where wedges started to grow as soon as the ground was exposed can be approximated.

Widths of wedges outlining polygons at 14 sites in Victoria Land were measured over an interval of 6 to 8 years, from 1961 to 1969 (Black 1973). During January 1982, Scott Ryan and I measured the same wedges again after a 12-year interval (late 1969 to January 1982) or, in one instance, a 13-year interval. Although only limited data analysis has been completed, it is clear that growth rates (that is, changes in widths of wedges) during the two intervals—the 6–8-year interval during the 1960's and the 12–13-year interval during the 1970's—differed markedly (table 1).

During the 1960's, the width of wedges increased a net average of 0.79 millimeter per year. (One site had a negative net average growth—that is, widths of wedges on the average decreased.) During the 1970's, 6 of the 14 sites had negative net-growth rates, and the average net growth of wedges at all sites was only 0.04 millimeter per year—a rate change of −0.75 millimeter per year from the earlier period. The only site exhibiting an increase in net-growth rate (0.04 millimeter per year)

Table 1. Rate of change of widths of wedges at 14 sites in Victoria Land. See Berg and Black (1966) and Black (1973) for exact locations and descriptions of sites.

Site	Growth from 1961 to 1969	Growth from 1969 to 1982	Net difference
Windy Crater	−0.39	−0.79	−0.40
Nussbaum-delta	+0.35	−0.79	−1.14
Nussbaum-hill	+0.34	−0.20	−0.54
New Harbor-delta	+0.89	+0.24	−0.65
New Harbor-moraine	+1.58	+0.76	−0.82
Beacon Valley-A	+0.82	+0.35	−0.47
Beacon Valley-B	+0.84	+0.58	−0.26
Cape Evans-ramp	+0.82	−1.17	−1.99
Cape Evans-base	+1.22	−0.01	−1.23
Wright Valley-A	+0.70	+0.38	−0.32
Wright Valley-B	+1.39	+0.78	−0.61
Wright Valley-C	+0.90	+0.33	−0.57
Wright Valley-D	+0.48	+0.52	+0.04
Hobbs	+1.09	−0.48	−1.57
Net average	+0.79	+0.04	−0.75

Note. All numbers are net average changes in millimeters per year.

Table 2. Preliminary computations of net average annual growth rates and computed ages of wedges in Victoria Land. No thermal or other corrections are included. See Berg and Black (1966) and Black (1973) for exact locations and descriptions of sites.

Site	Net average change (millimeters/year)[a]	Age (years)
Windy Crater	−0.44	N.D.[b]
Nussbaum-delta	−0.32	N.D.
Nussbaum-hill*	+0.06	12,500
New Harbor-delta	+0.51	1,380
New Harbor-moraine	+0.84	830
Beacon Valley-A	+0.53	5,990
Beacon Valley-B*	+0.68	5,000
Cape Evans-ramp	+0.17	3,235
Cape Evans-base	+0.14	2,890
Wright Valley-A*	+0.55	1,640
Wright Valley-B*	+1.00	2,000
Wright Valley-C*	+0.58	2,580
Wright Valley-D*	+0.56	720
Hobbs*	+0.03	9,490

[a] Twenty years of records available at unstarred sites; 19 years of records available at starred sites.

[b] N.D. = not determined.

Sand wedge exposed in cross section in higher terrace of the Onyx River, site C, Wright Valley (Berg and Black 1966, pp. 97–99).

since the 1960's adjoins a nearly perennial snowbank and stayed wetter than other sites.

The decreased rates of growth during the 1970's are attributed especially to warmer temperatures. Perennial snowbanks disappeared or became much smaller during the 1970's. At the one site where such measurements were made, the centers of polygons increased in width by a net average of 0.31 millimeter per year during the 1970's but decreased a net average of 0.20 millimeter per year during the 1960's. Warming of the permafrost accounts for the expansion of the centers of polygons and the shrinkage of many bordering wedges during the 1970's. Limited weather data from McMurdo (Naval Weather Service Detachment) support the warming trend.

Apparently, the bare, patterned ground of the arid to semiarid parts of Victoria Land is affected more by short-term fluctuations in climate and ground conditions than are the vegetated ice wedges of the more humid regions of northern Alaska. Consequently, antarctic wedges are less useful for dating purposes than are Alaskan wedges. For example, during the 1960's the computed ages of the wedges at the 13 sites exhibiting positive net average growth rates ranged from 280 years to 4,050 years (obtained by dividing average widths of wedges at a site by the positive net average annual growth rate) (Black 1973). For the 1970's the computed ages of the wedges at the eight sites exhibiting positive net average growth rates ranged from 770 to 9,140 years. The wedges at the 12 sites exhibiting positive net average growth rates over the 19 to 20 years of measurements (0.03 to 1.00 millimeter per year) have computed ages of 720 to 12,500 years (table 2). Only half the sites have wedges of sufficient uniformity of growth to lend confidence in the use of growth rates of wedges as a method of dating in Antarctica. Clearly, many decades of measurement are required to determine reasonably precise growth rates and ages over the lives of antarctic polygons. Conversely, dating by radioactive carbon in Alaska confirms the more generally uniform growth rates there.

In addition to the measurements of wedges, typical wedges were excavated by gasoline-powered jackhammer at all sites not previously excavated (figure). Samples have not yet been analyzed; nor have other data been evaluated. A planned summary paper of the long-term project will update that of Berg and Black (1966).

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Meteorite studies

Antarctic search for meteorites, 1981–1982

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The Antarctic Search for Meteorites (ANSMET) program in 1981–82 had seven participants. Besides the author, these were: Ursula Marvin of the Smithsonian Astrophysical Observatory; Ghislaine Crozaz of the Department of Earth and Planetary Science, Washington University; John Annexstad of the Lyndon B. Johnson Space Center; Robert Fudali of the Division of Meteorites, Smithsonian Institution; John Schutt of Salisbury & Dietz, Inc.; and Ludolf Schultz of the Max Planck Institut für Chemie.

The three main components of the ANSMET program were:

- *Field reconnaissance studies in northern Victoria Land.* We took advantage of the existence of the northern Victoria Land camp to make a reconnaissance survey of all likely looking possible meteorite concentration sites within helicopter range of the camp. A circular feature at Litell Rocks that could have been an impact crater had been identified in aerial photos, and this also was visited. Its mode of origin remains unknown.
- *Study of the relationship between the meteorite occurrence at Allan Hills and the dynamics of the ice regime there.* Questions about the relationship between ice dynamics and meteorite-concentrating mechanisms are of great interest because of the probability that greater understanding will aid in locating similar sites elsewhere and the certainty that answers to these questions will increase our understanding of ice sheet characteristics. Of relevance are age of the surface upon which meteorites are concentrated, ice-flow vectors and ablation rates, ice-to-bedrock relations, distribution of meteorites over the surface, and terrestrial ages of individual meteorites.

Annexstad and Schultz remapped the existing triangulation chain at Allan Hills and determined ablation rates for the previous year. A number of ice samples were obtained for E. L. Fireman for oxygen-18/oxygen-16 and carbon dioxide determinations. Attempts to determine ice thickness with a borrowed radio-echo sounder were unsuccessful, but Fudali made gravity measurements at all the triangulation stations and has been able to infer bedrock topography and ice thickness. Ian Whillans stopped briefly at Allan Hills to collect some firn and ice samples and contributed valuable insights about ice dynamics at the site.

- *Meteorite recovery at Allan Hills.* Meteorite recovery at Allan Hills continued and was carried out this year with increased attention to detailed mapping of the sites at which specimens were discovered. The other articles in this section contain more detailed accounts of the work summarized here.

At the end of the season it became possible to overfly the area around Thiel Mountains and Pecora Escarpment where extensive blue icefields exist. These sites may also contain metorites, and we hope to visit them as well as Allan Hills and Elephant Moraine during the 1982–83 field season.

Results of the antarctic search for meteorites, 1981–1982

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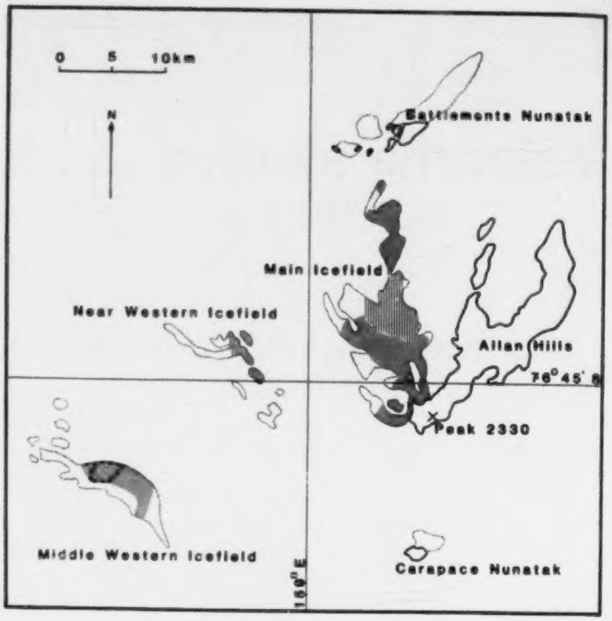
During the 1981–82 season the Antarctic Search for Meteorites (ANSMET) expedition had several objectives: (1) to conduct a reconnaissance survey of selected bare icefields within helicopter range of the northern Victoria Land camp, (2) to determine whether or not an anomalously circular feature at Litell Rocks in northern Victoria Land is a meteorite impact feature, (3) to search systematically the Main Icefield** at the Allan Hills, (4) to reconnoiter the three icefields to the west of the Allan Hills Main Icefield, (5) to resurvey the triangulation chain at the Allan Hills Main Icefield, and (6) to obtain gravity measurements at the triangulation chain stations.

Robert Fudali and I conducted the reconnaissance in northern Victoria Land during the period 24 November–15 December 1981. The reconnaissance searches were made mainly by helicopter, with occasional ground checks. Bare ice patches at the Lonely One Nunatak, Renirie Rocks, Emlen Peaks, Outback Nunataks, Johannessen Nunataks, Frontier Mountain, Onlooker Nunatak, and Monument Nunataks areas were visited as were icefields in the southern and western regions of the Daniels Range. A snowmobile traverse of the ice patches in the Gallipoli Heights area was also completed. No meteorites were found.

Although most of the reconnaissance was done by helicopter over bare ice patches with locally abundant terrestrial rocks, it was concluded that no large concentrations of meteorites similar to those found at the Allan Hills or Queen Fabiola Hills (Yamato Mountains) exist in the areas visited. A few observations may provide clues to explain this lack of similar sites. A broad, ridge-like topographic rise trending northeast-southwest, with its nose in the vicinity of the upper Rennick Glacier, is present in the east antarctic ice sheet. The east antarctic ice sheet appears to supply the Rennick Glacier with only a limited amount of ice, the bulk of the ice passing to the south and west. If large collecting areas are required to produce large concentrations of meteorites, the Rennick Glacier probably would not have such concentrations. A similar situation seems to exist in the Ellsworth Mountains region (Cassidy 1980).

Most of the meteorites recovered by U.S. efforts have been found on ablation surfaces upstream of partial or complete barriers to iceflow. In the areas visited in northern Victoria Land there were no such exposed icefields upstream. The Rennick Glacier is an active and vigorous glacial system because of the apparent relatively high accumulation rates in the region. Areas of stagnant ice probably are not extensive and are not likely to have been in a steady-state situation for the periods of time which appear to be necessary to form residual concentrations of meteorites (Cassidy and Rancitelli 1982).



Areas of the Allan Hills icefields explored by detailed, systematic grid search (line pattern) and on a reconnaissance level (dotted pattern) during the 1981–82 season. Heavy dashed line outlines the only area of the Middle Western Icefield where meteorites were found.

Fudali and I visited an anomalously circular feature at Litell Rocks (71°23'S 162°00'E). After a detailed inspection of the area, we concluded that the feature was not formed by meteorite impact. It apparently was formed by glacial processes.

The icefields in the Allan Hills (76°45'S 159°40'E) region, southern Victoria Land, were visited for a sixth season. John Annexstad and Ludolf Schultz were in the field from 12 November to 13 December. They resurveyed the triangulation network established during the 1978–79 season (Annexstad and Nishio 1979) and continued the yearly ablation measurements. Their results are reported in this issue of the *Antarctic Journal*.

Ursula Marvin, Fudali, Ghislaine Crozaz, W. A. Cassidy, and I were in the Allan Hills from 22 December 1981 to 23 January 1982. First we made snowmobile reconnaissance traverses to determine the areas of the icefields most likely to have the highest meteorite densities. Then, drawing on the results of the reconnaissance and on past experience in the Allan Hills, we made detailed, systematic grid searches of the most promising areas.

We searched portions of three separate icefields (figure). The Main Icefield, immediately west of the Allan Hills, had previously yielded the greatest number of meteorites from southern Victoria Land. Using the systematic search strategy, we recovered an additional 286 meteorite specimens from the Main Icefield.

We also searched systematically a portion of the Near Western Icefield, which lies approximately 20 kilometers west of the

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**The designations Main Icefield, Near Western Icefield, and Middle Western Icefield are not official names, but the features are distinct geographic units.

Preliminary tabulation and tentative identification of meteorite specimens recovered from the Allan Hills icefields, 1981–1982

	Classification					
	Ordinary chondrite	Carbonaceous chondrite	Achondrite	Stony-iron	Iron	Total
Main Icefield	275	2	8	0	1	286
Near Western Icefield	75	0	0	2	1	78
Middle Western Icefield	12	1	1	0	0	14
Total	362	3	9	2	2	378

Allan Hills, and recovered a total of 78 meteorite specimens. At least 52 of these are fragments of a single meteorite and may be similar to many of the 30 specimens recovered by helicopter searches in the same area during the 1977–78 and 1978–79 seasons (Cassidy 1978, 1979, personal communication).

A 1-day reconnaissance traverse was made to the Middle Western Icefield, located some 31 kilometers west-southwest of the Allan Hills, where 14 meteorite fragments representing 11 individual meteorites were recovered. Several other meteorites were found but not recovered because of poor weather and insufficient time.

A total of 378 meteorite specimens were recovered from the Allan Hills icefields during the 1981–82 season: 314 field sample numbers were issued, because in some cases two or more specimens were included in one collection bag. The table shows the preliminary tabulation of recoveries and tentative identification of the specimens.

Most of the locations where meteorites were found were determined by simple surveying methods. Detailed location maps currently being produced will prove useful in answering questions concerning the distribution of fragments of individual meteorites, meteorite distribution on the icefields, terrestrial age distributions across the field of occurrence, and the concentration mechanisms for meteorites on the icecap.

A gravity survey across the Allan Hills Main Icefield was undertaken and the data were used to calculate ice thickness and depth profiles. The results of this study are reported by Robert Fudali later in this section.

Ice samples were obtained for continuing carbon-14, carbon dioxide, and trapped-air studies.

Ian Whillans, of Ohio State University, joined the party for the last week in the field. He took a close look at the Allan Hills icefields and collected a number of ice samples for oxygen isotope and carbon dioxide studies.

This work was supported by National Science Foundation grant DPP 78-21104.

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Triangulation survey of the Allan Hills icefield, 1981–1982

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The triangulation network spanning 13 kilometers of the Allan Hills icefield was established in 1978 by a joint Japanese-American survey party (Annexstad and Nishio 1979). This 20-station network was remeasured in 1979, and the data on horizontal and vertical motion were published by Nishio and Annexstad in 1980.

An analysis of those survey data indicated that the icefield was essentially stagnant, but the values were considered preliminary because of measurement errors of nearly 100 percent. Consequently, it was decided to remeasure the network in 1981 to see if the percentage of error could be lowered.

We entered the field on 13 November 1981 and began measuring the network immediately. Clear weather and low winds prevailed for a few days, allowing us to complete initial ablation measurements and angular determinations at six stations. Inclement weather and high winds forced a cessation of survey operations for nearly 2 weeks, reducing the time available for fieldwork. The basic survey of the network was completed just prior to the 15 December 1981 flight back to the United States. Since we had to return to the United States on that flight, there was insufficient time to add a westward extension to the triangulation network.

Schultz is working to reduce the 1981 resurvey data as well as the data from previous seasons. Preliminary findings concerning the icefield's motion in the horizontal plane over 3 years are available, but the results concerning ice emergence (vertical motion) are not yet available. Analysis of the data obtained during the last three summer field seasons will continue during the next year.

Some conclusions can be drawn from the preliminary data:

- The Allan Hills icefield appears to be stagnant in the vicinity of high meteorite concentration.
- The ice flowing into the icefield from the plateau tends to decrease in velocity as it approaches the Allan Hills.
- Within the limits of measurement error, the annual rate of flow along the triangulation network is about 1 meter per year at the westernmost stations.
- Along the network, the ice flows toward the east for those stations located 5 kilometers or more to the west of the Allan Hills; the direction of flow for those stations closer to the Allan Hills is undefined.
- The annual rate of ablation averages about 4–5 centimeters.

In summary, it can be concluded that the Allan Hills icefield is essentially stagnant and has been a rather efficient concentrator of meteorite fragments.

This work is supported by the National Science Foundation, grant DPP 78-21104, the National Aeronautics and Space Administration, and the Max Plank Institut für Chemie.

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Gravity measurements across the Allan Hills main meteorite collecting area

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As part of the continuing effort to delineate the meteorite concentration mechanism at the Allan Hills, gravity measurements were made at all 24 stations of the previously established triangulation network across the main icefield (figure 1). Eight additional stations were occupied on bedrock from the northernmost tip of the Allan Hills south to Carapace Nunatak, to help define any regional gravity trend. Elevation control for these stations was provided by two Baromec barometers. The purpose of this project was to determine ice thicknesses and thus the configuration of the ice/bedrock interface beneath the triangulation network.

Attempts to measure ice thicknesses directly at Allan Hills have been largely unsuccessful. Using a U.S. Army Cold Regions Research and Engineering Laboratory 275–megahertz impulse radar profiling system (also called a radio-echo sounder), Kovacs (1980) measured the ice thickness at four points on the triangulation network. However, one of the points was very close to outcropping bedrock (making the ice thickness, naturally, very small), and the signal-to-noise ratio for two other measurements was so poor that the reported values are highly questionable (in fact, they are inconsistent with the new gravity data). Our field party tried using a similar radio-echo sounder at Allan Hills during January 1982, with no success. Kovacs' one radar-derived value that appears to be good gives an ice thickness of 130 meters at station 3. This provides a single calibration point for the gravity data.

The instrument used for the gravity survey was a LaCoste and Romberg model G meter (G–68). An ensulite sleeve fitted to the instrument afforded good protection from the wind without hampering operations. The instrument contained an internal heating element. When not in use, the sleeved instrument was kept in a heavily insulated box with the heat on continuously, 24 hours a day, during the 4-day survey. Nevertheless, instrument drift was 1 to 1.5 milligals per day (30 times the normal drift rate claimed by the manufacturer) and stations were reoccupied as often as possible to monitor this drift. In addition to drift corrections, the raw gravity data have been corrected for station differences in latitude and elevation and for a north-south regional trend of approximately 1 milligal per kilometer (decreasing to

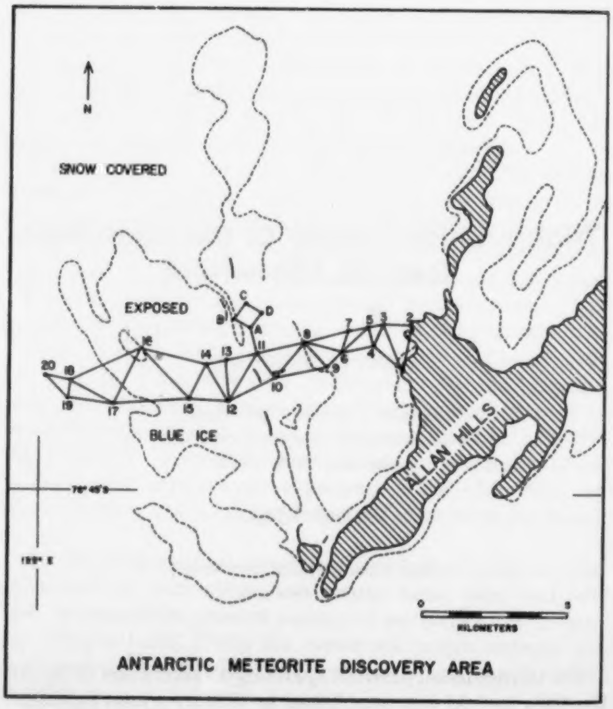

Figure 1. Allan Hills triangulation network.

Relative gravity values, depths to bedrock, and ice thickness at stations in the Allan Hills triangulation network

Station	Difference in gravity relative to station 2 (milligals)	Depth below datum to bedrock (meters)	Ice thickness above datum (meters)	Total ice thickness[a] (meters)
1	− 0.3	—	—	—
2	—	—	—	—
3	− 6.6	93	36	130
4	− 5.4	76	46	120
5	− 9.2	129	43	170
6	−19.3	271	44	315
7	−22.9	314	42	355
8	−36.5	512	37	550
9	−16.9	237	39	275
10	−19.5	274	35	310
11	−25.8	362	35	395
12	−21.2	297	121	420
13	−21.8	306	98	405
14	−26.6	373	104	475
15	−28.5	400	137	535
16	38.1	535	112	645
17	−35.1	492	165	655
18	−49.9	700	158	860
19	−53.7	753	165	920
20	−59.1	829	161	990
A	−29.7	416	16	430
B	−26.0	365	17	380
C	−31.2	437	11	450
D	−34.6	485	19	505

[a] Rounded to the nearest 0 or 5 in the third figure.

the south). Terrain effects were negligible for all stations except stations 1 and 2, where corrections of +2.0 and +0.5 milligals, respectively, were estimated on the basis of field observations and the two-dimensional technique of Hubbert (1948).

All gravity values reported in this article are relative to station 2, which was chosen as a convenient base station. This base also defines the elevation of the datum plane to which all the stations were brought by applying combined free-air and Bouguer elevation corrections. The use of relative data eliminates a major source of uncertainty in most antarctic gravity studies—the paucity of accurate absolute elevations. The corrected relative gravity values are listed in the table and are plotted as two east-west trending profiles in figure 2. The sharp drop of 60 milligals in the gravity profiles from east to west must largely reflect the slope of the ice/bedrock interface in this direction; there can be no significant slope to this interface in the north-south direction because there is no large, systematic offset between the two profiles.

If the regional gravity trend can be correctly removed, and if there are no significant local bedrock density contrasts, the ice thickness at each station can be calculated from the gravity data, provided only that the ice/bedrock density contrast is known. The north-south regional decline has been removed from the gravity signature; however, there are no data bearing on an east-west component of the regional trend. Nor is there any direct way of establishing the presence or absence of local bedrock anomalies, although, except for the dip defined by stations 7, 8, and 11, the reasonably smooth decline in the gravity profiles argues against the presence of any large local anomalies. For purposes of modeling the ice/bedrock interface, I have assumed no east-west regional trend and no local bedrock anomalies.

Differences in ice thickness (below the datum plane) between any two stations can be calculated from the formula:

$$\Delta t = \Delta g / 2\pi G \sigma,$$

where Δt is the difference in ice thickness and Δg is the difference in gravity between two stations, G is the gravitational constant, and σ is the ice/bedrock density contrast. When Δt is in meters and Δg is in milligals, the formula reduces to:

$$\Delta t = \Delta g / .04193 \sigma.$$

The formula is a variation of that used for calculating the effect of a horizontal sheet of infinite extent. For sloping surfaces, it is reputed (Nettleton 1976) to be accurate to better than 3 percent for slopes that are less than one in five (all the bedrock slopes calculated herein are less than one in five, and most are much less). In practice it is convenient to choose one station on bedrock ($t = 0$) to calculate ice thickness directly at the other stations. I have determined σ by simply varying its value in the second equation until the gravity-derived thickness approaches 130 meters at station 3 (the radar-derived value). The concomitant value of σ is 1.7 grams per cubic centimeter. Although it is only necessary that the ice/bedrock density *contrast* be known, it may be worth noting that the ice density is an invariable 0.9 grams per cubic centimeter, so the bedrock density should be 2.6 grams per cubic centimeter—close to the average crustal value of 2.67 commonly used for antarctic gravity reductions. Calculated ice thicknesses are given in the table and are plotted as profiles in figure 3.

If there is an east-west slant to the regional gravity field, its removal would systematically affect the bedrock profiles (figure 3) by pivoting them up or down about two horizontal north-south axes passing through stations 1 and 2. This would not change the profile shapes, only their tilt. Thus, any conclusions based on these profile shapes (figure 3) should be valid, whether or not there is an east-west trend.

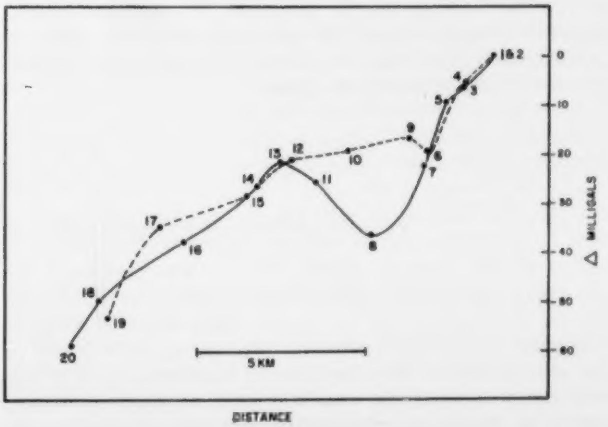

Figure 2. Projected gravity profiles along straight lines joining stations 2 and 20 (solid line) and 1 and 19 (dashed line).

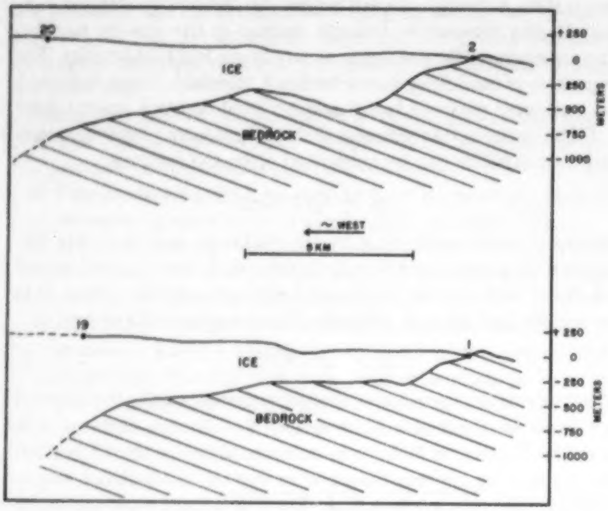

Figure 3. Profiles of the ice surface and the underlying ice/bedrock interface. Vertical exaggeration approximately 3 ×.

The one area where one could plausibly argue for a local negative bedrock anomaly is modeled as a basin imposed on the sloping bedrock surface in the upper profile (2–20). Whatever it is, it dies away rapidly to the southeast and also to the northwest (as evidenced by the gravity values at stations A, B, C, and D, which are not plotted on the profiles) and, therefore, cannot be a regional barrier to ice movement. It does, however, encompass the area that contained the highest density of meteorites, a gentle basin in the ice surface (not shown well by the profile stations). The lower profile (1–19) is more applicable to the entire area of interest.

Although the upper profile shows the "basin" situated directly in front of the ice surface monocline, the basin actually strikes obliquely away from the monocline in an east-southeast direction and cannot be a controlling factor in the monocline's development. The long, north-south trending ice monocline apparently has a much more subtle cause—the relatively low, gentle ridge situated directly below the monocline on both profiles. It is highly unlikely that this is coincidental; instead, it appears to be a good illustration of the effects of subtle bedrock structure on the overlying ice surface.

One can conclude from these profiles that if the (exposed) Allan Hills act as a barrier to ice movement, then clearly the barrier must begin much further west, where comparable bedrock slopes are present. This conclusion is consistent with the most recent surface reconnaissance which has delineated meteorite concentrations approximately 35 kilometers west of the Allan Hills. The presense of meteorite concentrations implies that horizontal ice movement is impeded at least this far away from the exposed barrier. However, the conclusion apparently conflicts with the preliminary horizontal ice flow rates determined by a resurvey of the triangulation network after 1 year. Nishio and Annexstad (1980) reported that horizontal ice movement varies from essentially zero immediately adjacent to the Allan Hills (exposed) barrier to a maximum of 2.5 meters per year at the western end of the network. Nishio and Annexstad also plotted horizontal direction vectors of ice movement and reported that vertical rates and surface ablation were comparable at a few centimeters per year. Taken at face value, these rates and directions indicate that there is an enormous amount of ice flowing into the main meteorite collecting area and very little ice flowing out or otherwise being removed. Given the incompressibility of ice, this seems to present an extremely unstable situation (analogous to blowing up a balloon) that could not be extrapolated backward in time very far. It will be interesting to see whether or not additional remeasurements confirm these reported ice movement rates and directions.

This work was supported by National Science Foundation grant DPP 78-21104 to W. A. Cassidy. I am indebted to the other members of the field party (Ghislaine Crozaz, Ursula Marvin, and John Schutt) for their aid in the survey, to R. Tingey (Bureau of Mineral Resources, Canberra) for loaning me the barometers, and to Claude Wessells (National Oceanic and Atmospheric Administration) for loaning me the G meter.

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Extraterrestrial microparticles from antarctic ice cores and the search for cometary dust

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Our attempt to find and identify cometary dust from antarctic ice cores of preindustrial age has been in progress for approximately 2 years. We began by characterizing various contaminants we would encounter by examining surface ice samples with the same analytical techniques, scanning electron microscopy, and energy dispersive X-ray analysis we would later apply to preindustrial-age samples. This type of database is essential for any type of microparticle work that is attempting to identify a possibly unique population of particles. Previous attempts to isolate and analyze any type of extraterrestrial particle from individual ice layers have failed, mostly because of the tremendous abundance of terrestrial particles in most sample intervals. Therefore, we chose to work with a core interval that has a relatively low total particle content (Mosley-Thompson and Thompson 1980), one that should contain particulate debris from the great Leonid meteor shower of 1833.

During the course of our layer-by-layer particle imaging and analysis, we found that the modal analyses of particle types in adjacent or different layers may be quite distinct. For example, one layer may be dominated by volcanic shards and spheres, while the adjacent layer contains mostly carbonate-rich loess grains. Also, particle morphology and grain size vary considerably from layer to layer. This offers the potential for building up reference dust lithostratigraphic sections for use in ice stratigraphy and chronology; however, this would be a very large task and is beyond the scope of the present work.

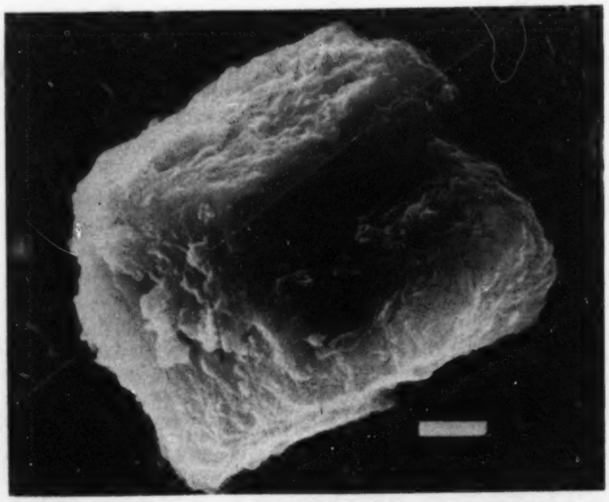

Figure 1. Scanning electron microscope image of a large meteoritic nickel-iron particle showing crude hexahedral cleavage. The nickel-to-iron ratio is approximately 1:10. The particle is mounted on nucleopore filter paper; scale bar = approximately 2 micrometers.

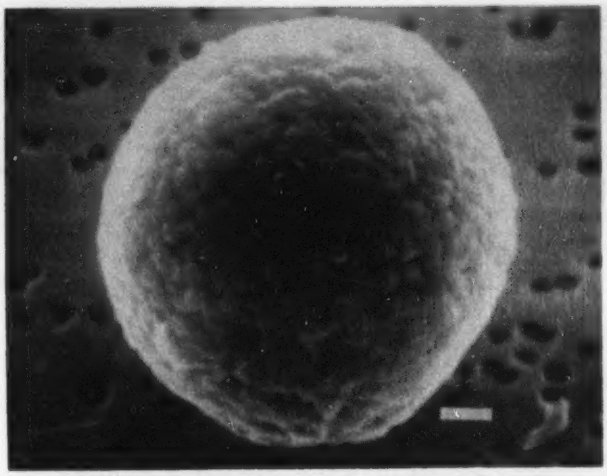

Figure 2. Scanning electron microscope image of a sphere composed almost entirely of iron oxide (probably magnetite) with a very minor amount of sulfur. Probably a meteoritic ablation spherule; scale bar = approximately 1 micrometer.

Of more immediate interest is the discovery of extraterrestrial microparticles in a number of the ice core samples. Initial descriptions and analyses of the particles (King and Wagstaff 1982; Wagstaff and King 1981a, 1981b, King and Wagstaff 1980) show that most are common types of meteoritic material (figures 1 and 2). It appears that we are finding particles of extraterrestrial materials that are very similar or identical to those now being collected in the stratosphere (e.g., Brownlee et al. 1976; Cosmic Dust Preliminary Examination Team 1982). Thus our preliminary data indicate that there is no major difference between the extraterrestrial materials that were entering the Earth's atmosphere in 1833 and those encountering the Earth at present. The possibility should be considered that some (many?) particles we have imaged and analyzed *are* cometary debris, that is, that cometary particles are identical to some common types of meteoritic particles. Wood and Mendell (1982) have recently made such a proposal on both observational and theoretical grounds. If, after collecting data from a large number of extraterrestrial particles from this stratigraphic interval, we still find only normal meteoritic materials, our data will strongly support their model.

One of the most commonly cited candidates for cometary material is carbonaceous chondrite. In our preparatory studies, we examined grains from gently crushed carbonaceous chondrites and found identical grains in dust samples from the antarctic ice cores (figure 3).

We still must examine enough total grains and extraterrestrial grains to get statistically significant data. However, this will require a substantial amount of time, as in even the most abundant sample intervals extraterrestrial grains are only about one particle in ten thousand.

This work is supported by National Science Foundation grant DPP 78-20410.

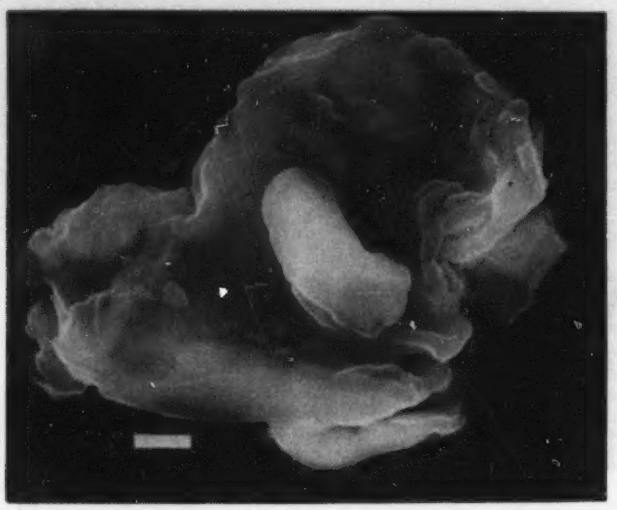

Figure 3. Scanning electron microscope image of a large irregular particle that is carbon-rich. It contains discrete inclusions of iron sulfide and iron-magnesium silicates 1 to 2 micrometers in diameter embedded in a carbon-rich matrix that appears to be amorphous. Scale bar = approximately 2 micrometers. Similar particles are found in gently disaggregated carbonaceous chondrites.

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Victoria Land meteorite collections, 1980–1981

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During the 1980–81 field season, a U.S. party collected 32 meteorite specimens in the Allan Hills (ALH) area, 67 near Reckling Peak (RKP), and 1 near Outpost Nunatak (OTT) (Cassidy and Annexstad 1981).* These specimens have been classified as follows: irons, 2; mesosiderites, 4; eucrites, 3; ureilite, 1; chondrites, 90. The chondrites belong to the following classes and types: carbonaceous—C3, 1; olivine-bronzite—H3, 2; H4, 7; H5, 25; H6, 18; olivine-hypersthene—L3, 3; L4, 2; L5, 3; L6, 22; LL5, 2; LL6, 4; and enstatite—E5, 1. The mesosiderites are paired with RKPA79015 (originally classified as an iron with silicate inclusions); 15 L6 chondrites from the Allan Hills appear to be pieces of a single meteorite; several of the L6 chondrites from Reckling Peak are paired with RKPA78001; and 13 H6 chondrites from Reckling Peak appear to be pieces of a single meteorite. Additional pairings are possible on further examination.

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*Figures differ slightly from those reported by Cassidy and Annexstad. Their figure of 69 specimens collected near Reckling Peak included 1 collected near Outpost Nunatak; in addition, 1 specimen reported from near Reckling Peak and 2 from the Allan Hills were determined not to be meteorites.

Seymour Island expedition

First U.S. expedition to the James Ross Island area, Antarctic Peninsula

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The Seymour Island expedition to the James Ross Island area was the first major U.S.-supported field program along the northeastern flank of the Antarctic Peninsula (figure 1). The expedition was also the first time a U.S. Coast Guard icebreaker was used to support a geological field program. The success of the Seymour Island expedition clearly confirms the feasibility of using icebreakers to support onshore field programs. The combined mobility of the ship and its helicopters opens vast areas of the Antarctic Peninsula that have been inaccessible in the past. This article summarizes briefly the field season and the significant discoveries made on Seymour Island.

The USCGC *Glacier* departed Punta Arenas for Seymour Island on 14 February 1982. The schedule called for putting the field party ashore as soon as possible and then carrying out an onboard marine geology program directed by John B. Anderson, Rice University, in the Bransfield Strait. Later in the season, *Glacier* was to return to the Seymour Island area and provide helicopter support for reconnaissance surveys to Snow Hill and to Vega and James Ross Islands in preparation for future studies.

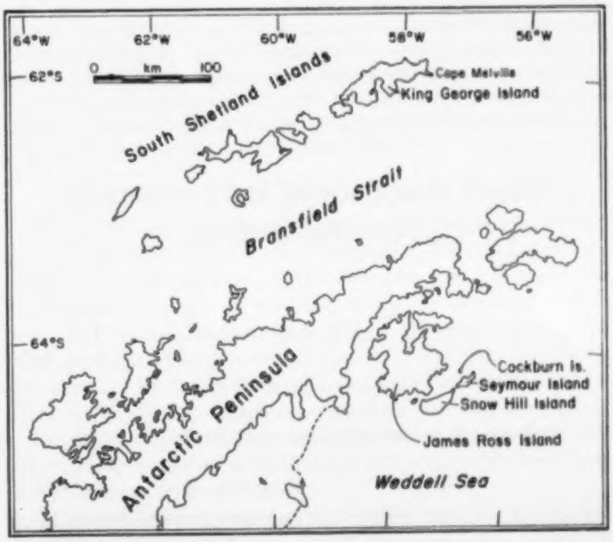
One brief stop was made in the South Shetland Islands, at Cape Melville (north end of King George Island) (figure 1), to visit a Tertiary sequence discovered by a Polish field party during the 1980–81 field season. The purpose of the visit was to obtain samples for study in preparation for future fieldwork at Cape Melville.

Glacier arrived at Seymour Island on the morning of 19 February. Helicopters transported personnel and field equipment to the main campsite on the south side of Cross Valley (figure 2). A second, smaller camp was established at the southern end of the island to facilitate work on the Cretaceous deposits exposed there. Weather during late February and early March was surprisingly good, and only 3 days out of the 19-day field season were lost because of storms. *Glacier* returned on 7 March, and helicopters immediately transported samples and nonessential equipment back to the ship. A reconnaissance party was also flown to the northern end of Snow Hill Island on the 7th. The schedule called for *Glacier* to provide helicopter support to the nearby islands for the next 3 days, but a sudden storm required the immediate evacuation of the parties from both Seymour and Snow Islands. Before the ship returned to Punta Arenas, weather conditions improved sufficiently to allow several short visits on the 9th to Cockburn, Vega, and James Ross Islands.

Results of the Seymour Island expedition included:

- First discovery of Tertiary reptiles (lizards) from Antarctica.
- First discovery of bony fishes (holosteans) from the Cretaceous of Antarctica.
- First discovery of a Tertiary coal seam in Antarctica, in the Cross Valley Formation.
- Discovery of several large skeletons of plesiosaurs.
- Discovery of skeletal remains of a mosasaur (a partial skull was recovered).
- Recognition of at least 300 meters of additional Tertiary marine sediments on Seymour Island.
- Completion of the first systematic palnyological sampling of both the Cretaceous and Tertiary deposits on Seymour Island.

Figure 1. Index map of the northern end of the Antarctic Peninsula.



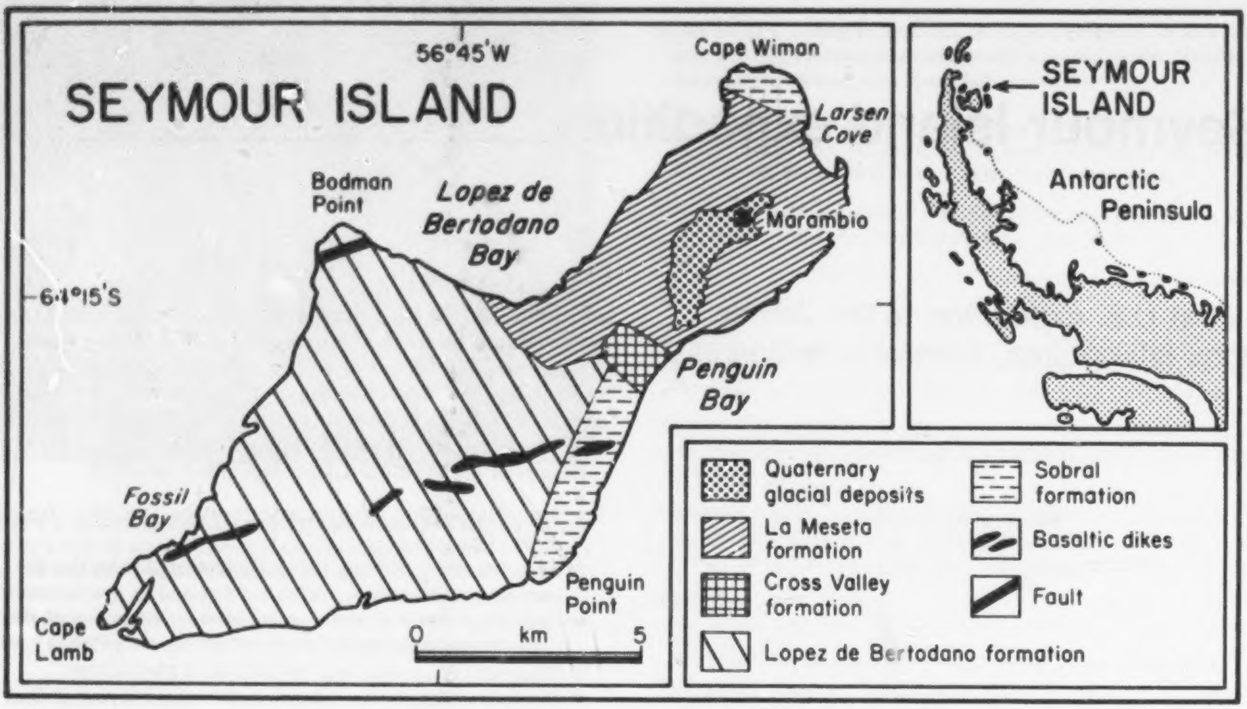

SEYMOUR ISLAND
56°45'W
64°15'S
Cape Wiman
Larsen Cove
Bodman Point
Lopez de Bertodano Bay
Marambio
Penguin Bay
Penguin Point
Fossil Bay
Cape Lamb
0 km 5
SEYMOUR ISLAND
Antarctic Peninsula
Quaternary glacial deposits
La Meseta formation
Cross Valley formation
Lopez de Bertodano formation
Sobral formation
Basaltic dikes
Fault

Figure 2. Index map of Seymour Island.

- Collection of large quantities of marine invertebrates and vertebrates from the Tertiary La Meseta Formation.

The Seymour Island field party comprised William J. Zinsmeister, Thomas DeVries, Carlos Macellari, and Brian Huber, Institute of Polar Studies, Ohio State University; Michael O. Woodburne and William Daily, Department of Earth Sciences, University of California, Riverside; Rosemary Askin, Colorado School of Mines; Farley Fleming, Department of Geological Sciences, University of Colorado; Sankar Chatterjee, The Museum, Texas Tech University; and Gary Wilhite, USCGC *Glacier*.

The Seymour Island expedition was supported by the following National Science Foundation grants: W. J. Zinsmeister, DPP 80-20069; Sankar Chatterjee, DPP 80-20096 and DPP 81-07152; Rosemary Askin, DPP 80-20095; and Peter N. Webb, DPP 79-07043.

Newly discovered land mammal from Antarctica

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This notice records for the first time the presence of fossil land mammals on the Antarctic Continent. The remains, considered on the basis of associated megafossil and microfossil invertebrates and pollen to be of late Eocene age (about 40 million years old), were recovered from a unit of thinly bedded arkosic sandstone near the top of unit II, 510 meters above the base of the La Meseta Formation in northwestern Seymour Island (figure 1).

The fossils are referable to the extinct marsupial family Polydolopidae, known previously from strata of late Paleocene to early Oligocene age in Patagonia, Bolivia, and Brazil (Patterson and Marshall 1978; de Paula Couto 1952; Simpson 1948).

As presently identified, the polydolopid remains consist of a left mandible with lower third premolar-lower second molar (P_3-M_2) and alveolus for lower third molar (M_3) (figure 2), a right mandible fragment with lower third premolar-lower first molar (P_3-M_1), and isolated upper first molar (LM^1) and upper second molar (LM^2). The specimens show that the third lower premolar was laterally compressed for cutting, whereas the upper and lower molars had a relatively flat grinding surface bounded by many small cusps. This morphology most closely resembles that found in the genus *Polydolops*, as described by Simpson (1948) and de Paula Couto (1952), but differs from most species of that genus in the apparent absence of lower second premolars (P_2), in the more elongate proportions of the molars, and in details of their coronal morphology. The isolated upper teeth in some ways resemble those of *Amphidolops*, known from Eocene strata in South America (de Paula Couto 1952), but they could have been modified from the condition seen in *Polydolops*. If all upper and lower polydolopid teeth found on Seymour Island pertain to a single species, that species reveals a combination of characteristics unknown in South American forms.

The antarctic fossils clearly suggest the presence of a former land connection (or a series of closely spaced islands separated by shallow water) between the peninsula and South America. It is difficult at present to narrow the timing of such a connection beyond an interval from the late Paleocene (when polydolopids first are known from South America) to the late Eocene (when they are now known from Antarctica), or from about 55 to 40 million years ago.

The newly discovered materials thus confirm general theories as to past marsupial distribution (Clemens 1977; Marshall 1980; Tedford 1974), which predicted the presence of those animals in Antarctica in the Late Cretaceous or early Cenozoic. On the other hand, the Seymour Island fossils pertain to a marsupial group that is evolutionarily derived, and adaptively divergent, from the generalized and primitive marsupial type. This basal stock is represented in South and North America by the Didelphidae (opossums), of Late Cretaceous and later age, and in Australia by the Dasyuridae ("native mice"), of late Miocene age there but certainly of earlier origin. In fact, the endemic marsupial radiation in Australia was well established by that time (approximately 25 million years ago) and must have stemmed from an older radiation rooted in an early didelphid (in morphology if not in name). This ancestral group must have been present in Australia prior to the time it separated from Antarctica, about 55 million years ago. It is not clear yet whether the ancestral didelphid arose in Australia and dispersed via Antarctica to the Americas or vice versa. In either case, one might have expected that the fossils most likely to be found in Antarctica would pertain to this basal stock. The polydolopid fossils are a delightful surprise.

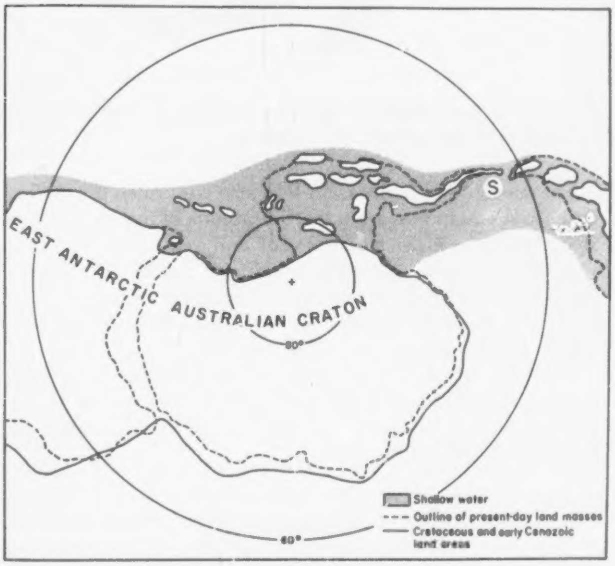
S
EAST ANTARCTIC AUSTRALIAN CRATON
60°
60°
Shallow water
Outline of present-day land masses
Cretaceous and early Cenozoic land areas

Figure 1. Reconstructed relationship of Antarctica and adjacent areas in the Late Cretaceous, showing broad continuity between East Antarctica and Australia, the possibly discontinuous antarctic archipelago, the approximate location of Seymour Island (S), and the southern tip of South America (modified from Zinsmeister 1982). The general relationships shown here probably persisted until about 55 million years ago, when Australia separated from Antarctica. Until that time, the antarctic archipelago apparently operated as a filter to dispersal between South America and Australia. Dispersal up to at least 50 million years ago between South America and the archipelago is documented by the newly discovered polydolopid remains.

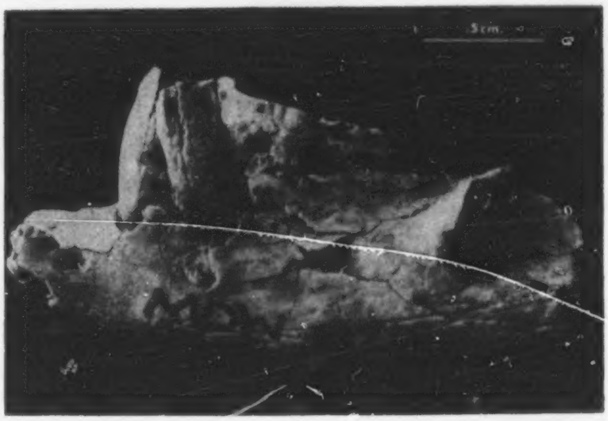

Figure 2. Lateral view of the left lower jaw of the polydolopid from the La Meseta Formation (upper Eocene), Seymour Island, Antarctic Peninsula. The teeth are the last premolar, which is plagiaulacoid (compressed laterally, and blade-like for cutting), and the first two molars (grinding teeth). Alveoli (holes) for the roots of the last molar are visible behind the second. MOW 8212 is the field number given at the time the fossil was collected on 5 March 1982. Scale shows that the specimen is about 15 millimeters long.

Thus, the new Seymour Island fossils establish the presence of marsupials in the Antarctic Peninsula in the late Eocene and suggest that the land connection between this area and South America was closer or firmer than usually depicted in map reconstructions based on submarine (sea-floor spreading) data. The Seymour Island materials point up the faunal similarity between South America and the Antarctic Peninsula in the late Eocene but do not contribute directly to answering questions concerning earlier marsupial distribution in the southern continents. The evidence is tantalizing, but more work needs to be done to verify the relationship.

This work was supported in part by National Science Foundation grant DPP 80-20069.

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Late Cretaceous marine vertebrates from Seymour Island, Antarctic Peninsula

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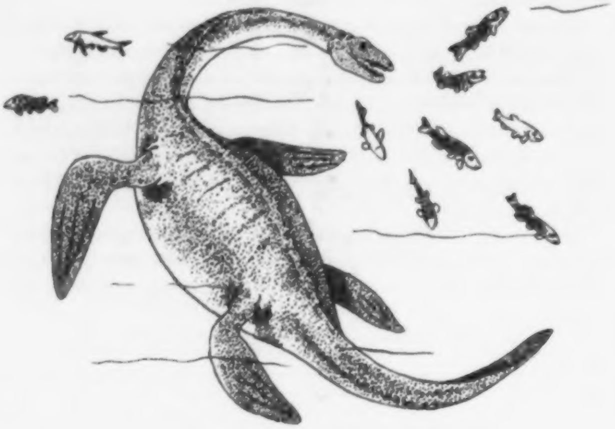
Geological fieldwork on Seymour Island during the 1981–82 austral summer led to the discovery of several interesting marine vertebrates from the Late Cretaceous Lopez de Bertodano Formation of the Marambio Group. These include bony fishes, sharks, and the reptilian suborders Plesiosauria and Mosasauria.

The Lopez de Bertodano Formation consists of 1,067 meters of gently eastward-dipping, loosely consolidated sandstones and sandy siltstones which crop out in the southern two-thirds of Seymour Island. The invertebrate fauna is varied, consisting of ammonites, echinoids, bivalves, gastropods, and arthropods, and suggests Middle Campanian to possibly Maestrichtian Age (Rinaldi et al. 1978). Fish debris and bone fragments of marine reptiles were encountered occasionally, but due to incompleteness of the material the vertebrate remains, until recently, were not fully diagnostic.

Abundant specimens of bony fishes (holosteans), including several skulls, were found for the first time. The shark specimens are represented by isolated teeth, a calcified jaw, and associated calcified vertebrae. The vertebrae are amphicoelous, short antero-posteriorly, showing concentric lamellae. Woodward (1906) referred similar vertebrae to the genus *Ptychodus*, but the identification has been questioned (Welton and Zinsmeister 1980).

The first antarctic plesiosaur, represented by fragmentary material from the Late Cretaceous of James Ross Island, is of limited diagnostic value (del Valle, Medina, and de Brandoni 1977). The new material represents at least two individuals, one perhaps 7.5 meters long and the other up to 15 meters (figure). It consists of articulated vertebrae and associated girdle and limb elements, and we are hopeful that it will allow finer diagnosis.



The great marine reptile of the Late Cretaceous; this plesiosaur probably reached a length of 15 meters.

The presence of a mosasaur was also confirmed for the first time from Antarctica, from the Cretaceous of Seymour Island. The material includes a partial skull and associated procoelous vertebrae and limb elements. The abundance of vertebrates at Seymour Island ensures that further intensive collecting would serve both to greatly expand the faunal list and to acquire more morphologic information on the taxa already identified.

This research is supported by National Science Foundation grants DPP 80-20096 and DPP 81-07152. We thank Gary P. Wilhite for assistance in the field, Nicholas Hotton for discussion, and Michael Nickell for illustration.

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Early Tertiary coal bed on Seymour Island, Antarctic Peninsula

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A coal seam was discovered on Seymour Island, Antarctic Peninsula, during the course of geological fieldwork in March 1982. The seam is tentatively assigned to the early Tertiary Cross Valley Formation and is apparently the first discovery of a Tertiary coal bed in Antarctica.

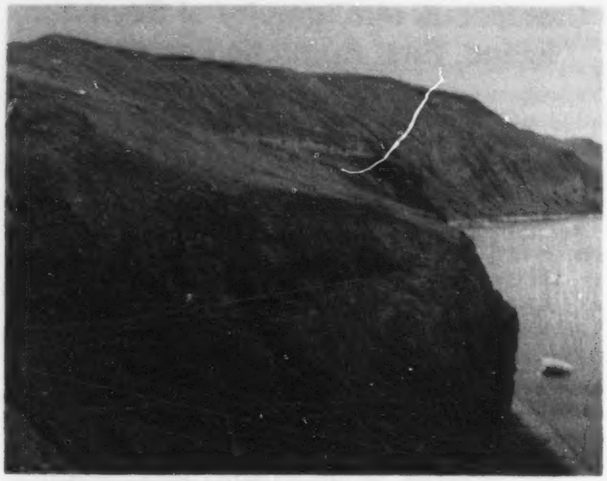
The coal seam is exposed on a precipitous, scree-covered seacliff (see figure) just south of Cross Valley on the eastern coast of Seymour Island. Field relationships suggest that the coal-bearing sediments are equivalent to the upper, fine-grained portion of the Cross Valley Formation, but because of the inaccessibility of the exposure we were unable to measure the section containing the seam.

The exposed seam is approximately 1 meter thick and 6 meters long and contains coalified logs. Several thin, discontinuous, clay partings occur within the seam, and the sediments overlying and underlying the coal consist of fine to medium sands. In the examined (southern) portion, an apparently discontinuous layer of dark gray clay (2 centimeters thick) occurs at the base of the coal.

Fourteen channel samples from the coal seam were collected for palynological, petrographic, and other analyses. Vitrinite reflectance averages of 0.28 percent Ro and 0.30 percent Ro suggest that the coal is a lignite (American Society for Testing Materials scale; see table 4, Stach et al. 1975). Palynomorphs recovered are light yellow, exhibiting a low level of thermal alteration which also suggests a low rank for the coal.

Initial palynological processing of two channel samples yielded abundant, well-preserved pollen grains, rare fern spores, and no marine palynomorphs. The assemblage is dominated by podocarpaceous pollen, mainly *Phyllocladidites* spp., and also contains angiosperm pollen, including *Nothofagidites* spp., proteaceous species, and a tricolpate species (see F in figure, Askin and Fleming, *Antarctic Journal*, this issue) which apparently is restricted to the Sobral and Cross Valley Formations.

Cranwell (1969) suggests a Maestrichtian to Paleocene age for palynomorphs from the Cross Valley Formation. Wrenn (1982), on the basis of dinoflagellates, suggests that the Cross Valley Formation is Paleocene-Eocene in age. Elliot and Trautman (1982) interpreted the upper, fine-grained part of the Cross Valley Formation as deposited in low-energy interdistributary areas of a delta. Future studies of this coal seam could provide valuable information on the floral components and climatic factors of the early Tertiary in the Antarctic Peninsula area and could aid in the interpretation of the depositional environment of the Cross Valley Formation.



View of coal seam in upper seacliff south of Cross Valley.

We thank other members of the expedition, particularly William J. Zinsmeister, for locating the coal seam, the captain and crew of USCGC *Glacier* for logistic support, and Tom Hemler (Amoco Production, Denver) and Mel Thompson (Chevron U.S.A., Denver) for vitrinite reflectance data. This work was supported by National Science Foundation grant DPP 80-20095.

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Cretaceous stratigraphy of Seymour Island, East Antarctic Peninsula

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The Cretaceous stratigraphy of Seymour Island (Isla Vicecomodoro Marambio in Argentine literature) has been described by Andersson (1906) and more recently by several authors (Elliot et al. 1975, Rinaldi 1982, and Rinaldi et al. 1972, among others). However, no detailed sedimentological or stratigraphic account of these sediments has yet been published. As one of the programs on the Seymour Island Expedition, we undertook a comprehensive survey of the Cretaceous portion of the island. The objectives of this study were to provide the first detailed sedimentological description and a detailed geologic map of the Upper Cretaceous section, as well as to collect micro- and macropaleontological samples in order to refine the present zonation of the sequence. Correlation with other faunas from the Southern Hemisphere will then be attempted, primarily on the basis of the foraminiferal and molluscan specimens.

Four profiles were measured on Seymour Island in areas of little tectonic disturbance, previously selected by photointerpretation (figure 1). A total of 250 samples were systematically collected within these profiles at approximately 10-meter intervals. Good weather and invaluable support from the helicopter pilots and the crew of the USCGC *Glacier* made it possible to visit and measure profiles on Snow Hill, Vega, and James Ross Islands in addition to the planned activities on Seymour Island. We hope these observations and samples will provide valuable information regarding the correlation of different Cretaceous outcrops within the James Ross Island area. They may be particularly helpful in establishing a detailed correlation between the Seymour and Snow Hill Island sequences.

The oldest unit exposed on the island is the Lopez de Bertodano Formation of Campanian (Howarth 1966; Olivero 1981) to possibly Maestrichtian (Spath 1953) age (figure 2). The maximum measured thickness was encountered in profile I (1,190 meters). Several minor units were recognized on the basis of lithology, degree of cementation, and fossil content; many of these were laterally continuous throughout the island. In general, the predominant lithology is composed of monotonous, gray, friable, sandy siltstones. Sporadic intercalations of calcareous, indurated fine-grained sandstones occur within the sandy siltstone units, resulting in a more positive relief. Rounded to irregular concretions and concretionary horizons are found throughout the sequence. With the exception of the lower 300 meters of the section, fossils are extremely abundant and very well preserved. Different and laterally persistent mac-

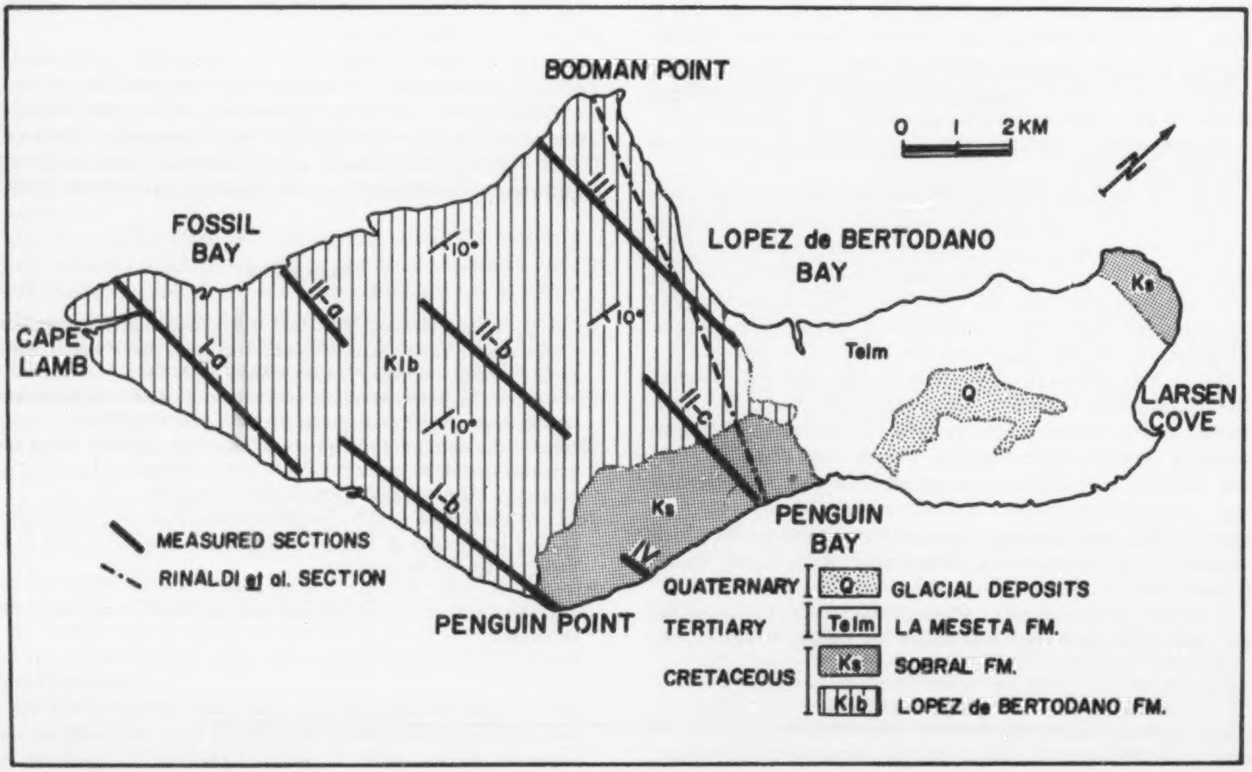

Figure 1. Simplified geologic map of Seymour Island showing location of measured sections (after Rinaldi et al. 1978).

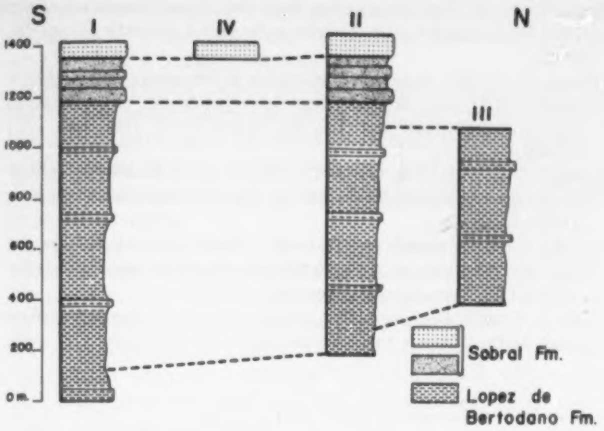

Figure 2. General correlation between sections measured on Seymour Island.

rofaunal assemblages were recognized, including numerous ammonites, bivalves, gastropods, echinoderms, corals, and sporadic fossil wood. Large benthic foraminifera were recognized in the field within the unconsolidated strata, where faunal diversity appeared to be quite low. Preliminary observations indicate that the foraminiferal population is more abundant in the lower three-quarters of the Upper Cretaceous sequence.

The Sobral Formation, which may be Maestrichtian to Paleocene in age, overlies the Lopez de Bertodano Formation in an apparently concordant fashion. It consists of up to 265 meters of somewhat coarser and more glauconitic silty sandstone, grading into fine-grained sandstones. Rounded concretions and concretionary horizons are frequent. Some beds are laterally continuous, but generally this formation shows a more pronounced lateral variation than the previous unit. The base of the Sobral Formation is a laterally continuous, 15–20-meter thick, dark brown, well-laminated to flaser-bedded silty mudstone which displays local channels. This moderately resistant bed produces a conspicuous positive break in the topography (figure 3). A continuous, well-cemented, large-scale trough cross-bedded glauconitic sandstone appears at approximately 180 meters from the base of the Sobral. Above this, the sequence becomes more sandy, glauconitic, and occasionally yellow-stained, with increasingly abundant concretions and fossil wood. All of these characteristics indicate that this may be an independent unit lithologically similar to the Cross Valley Formation (Elliot et al. 1975). Fossils found in the Sobral Formation

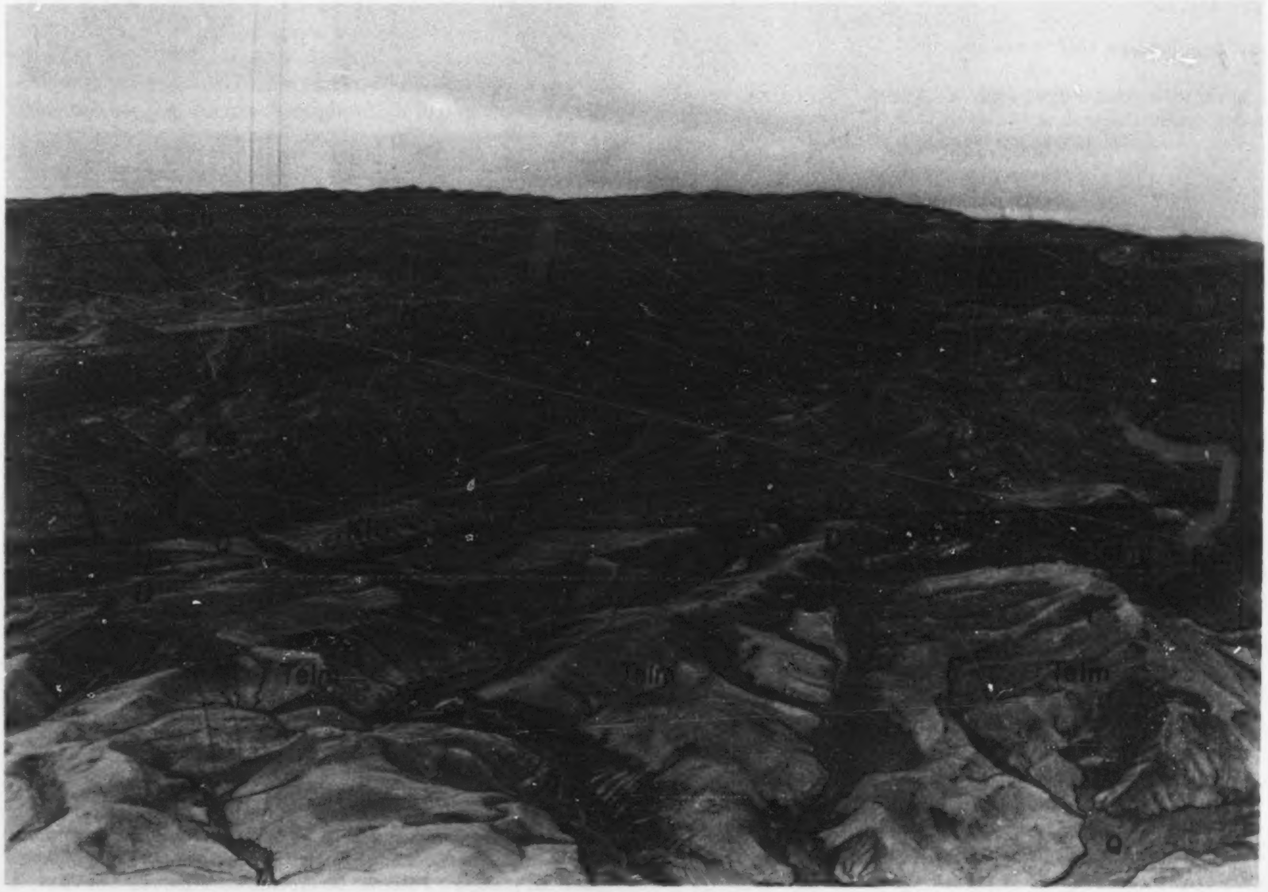

Figure 3. Oblique aerial photograph showing the major units recognized in the Cretaceous of Seymour Island, and the unconformable contact with the Tertiary La Meseta Formation: Klb = Lopez de Bertodano Formation; Ks = Sobral Formation; Ksu = upper unit of the Sobral Formation; Telm = La Meseta Formation; Q = undifferentiated Quaternary deposits. (Photograph by W. J. Zinsmeister)

include bivalves, gastropods, echinoderm spines, and abundant wood.

This work was supported by National Science Foundation grant DPP 80-20096.

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Palynological investigations of Campanian to lower Oligocene sediments on Seymour Island, Antarctic Peninsula

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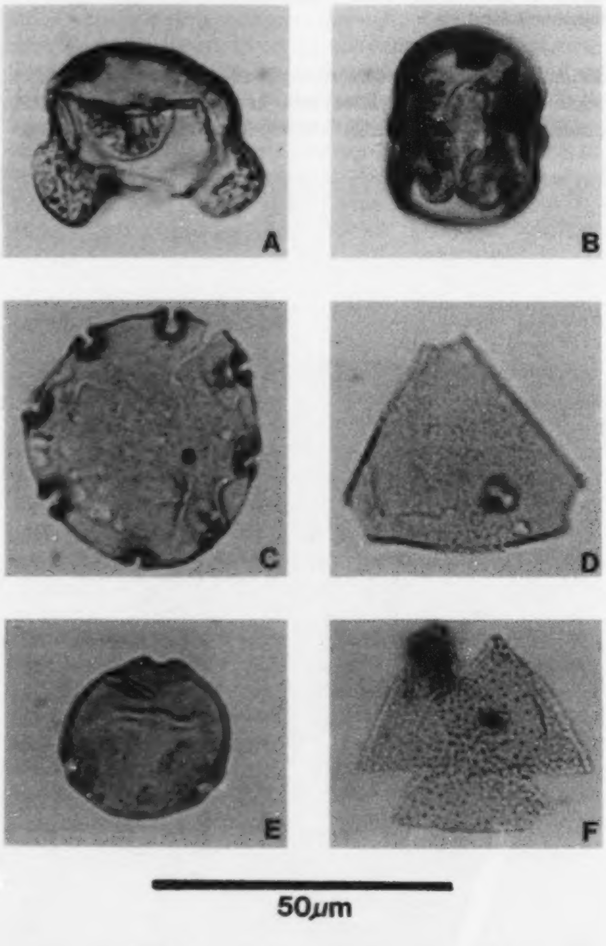
Palynomorphs have been recovered from all of the first preparations of samples collected during the February–March 1982 expedition to Seymour Island. In all, 363 samples were collected, mainly from Seymour Island but also from Snow Hill Island (provided by B. Huber), Cape Lamb on Vega Island, The Naze on northeastern James Ross Island, and Cape Melville on King George Island.

The stratigraphy of Seymour Island is summarized by Macellari and Huber (*Antarctic Journal*, this issue; Campanian to ? Paleocene, Lopez de Bertodano and Sobral Formations) and by Zinsmeister and DeVries (*Antarctic Journal*, this issue; ? Paleocene to lower Oligocene, Seymour Island Group). Apart from cemented resistant sandstone beds and concretions, most of the sedimentary sequence on Seymour Island is unconsolidated. Fine-grained sediments (mud and silt) are abundant in places particularly in the Sobral Formation. Much of the fine-grained sediment is carbonaceous and highly suitable for palynological sampling.

The best continuously exposed section of predominantly fine-grained sediment crops out in the central part of Seymour Island. This approximately 300-meter-thick section includes the Sobral Formation and is believed to include the Cretaceous-



Photomicrographs of fossil pollen from Seymour Island (bar is equivalent to 50 micrometers). A, *Microcachryidites antarcticus* Cookson; B, *Phyllocladidites mawsonii* Cookson; C, *Nothofagidites flemingii* (Couper) Potonié; D, *Proteacidites parvus* Cookson; E, *Haloragacidites harrisii* (Couper) Harris; F, *Tricolpates* sp. A, B, D, and E occur in the Sobral Formation and throughout the Seymour Island Group; C occurs in the Seymour Island Group; and F occurs in the Sobral Formation and the Cross Valley Formation.

Tertiary boundary. Over much of this section it was possible to collect at 1.5-meter intervals; for most of the remainder, we could collect at 3-meter intervals.

Cretaceous strata (Lopez de Bertodano Formation) cropping out on the southwestern part of the island are characterized by low topographic relief (in comparison with the rest of the island), and much of the strata is covered with debris; therefore, continuous sampling for palynomorphs was not possible in the older sandy units.

Sampling was carried out throughout the Cross Valley Formation, although horizons suitable for palynomorphs are rare in the predominantly coarse-grained lower part of the formation. A coal bed presumed to be included in the Cross Valley Formation (see Fleming and Askin, *Antarctic Journal*, this issue) was sampled, as was much of the La Meseta Formation, including a unit adjacent to the marsupial bone locality (see Woodburne, *Antarctic Journal*, this issue).

Distinct palynomorph assemblages are recognized from samples provided by the 1974–75 expedition of Elliot and others (1975) and our recent collections (figure). Podocarpaceous pollen predominates in Sobral Formation sediments, with less common *Nothofagidites* spp. (*fusca* and *brassi* groups), some proteaceous species, and pteridophyte spores. In the Seymour Island Group, podocarpaceous species and *Nothofagidites* spp. (*fusca*, *brassi*, and *menziesii* groups) are dominant; proteaceous pollen is often abundant but shows a noticeable decline in relative abundance in the upper part of the La Meseta Formation. A succession of other distinctive and previously undescribed angiosperm pollen, some of which appear to have restricted ranges, occurs throughout. A few of these species also occur in the Ross Sea region (Truswell personal communication), but some may have been endemic to the Seymour Island region. Simple tricolpate species are common in Sobral Formation samples.

In summary, a good, representative sampling for palynomorphs on Seymour Island has been obtained. These samples may provide both a palynostratigraphic zonation and information on the changing vegetation and paleoenvironmental conditions in the area.

We thank fellow members of the expedition for companionship and enthusiastic support, and Captain Coste and the crew of USCGC *Glacier* for logistic support. This research is funded by National Science Foundation grant DPP 80-20095.

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Observations on the stratigraphy of the lower Tertiary Seymour Island Group, Seymour Island, Antarctic Peninsula

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The 1981–82 geological program on the Tertiary of the Seymour Island Group represents a continuation of fieldwork initiated on Seymour Island by a joint U.S.-Argentina expedition during the austral summer of 1974–75 (Elliot et al. 1975). Results of the fieldwork this year have greatly enhanced our knowledge of the Tertiary succession on Seymour Island and the stratigraphic relationships between the Tertiary and the underlying Upper Cretaceous Marambio Group. The most significant events were recognition of approximately 300 meters of additional sediments in the lower part of the La Meseta Formation in Cross Valley and verification of the formation's unconformable relationship with the underlying Cretaceous.

During the 1974–75 field season, Elliot and Trautman (1982) determined that the La Meseta Formation has a thickness of about 450 meters. Because of the faulted nature of the basal contacts of the sections they measured at the northern end of the island, it was suggested that the formation was probably thicker. Work this year around Cross Valley (figure 1) revealed approximately 300 meters of additional sandy siltstones referable to unit I of the La Meseta.

These sediments are characterized by finely laminated to thinly bedded sandy siltstones with clayey sands. Several fossiliferous, coarser, sandy facies similar to the shell banks of unit II were encountered approximately 200 meters above the base. Lenticular beds near the western mouth of Cross Valley contained moderately abundant leaf impressions and fish scales, as well as marine mollusks. Fossilized logs, which are common in the overlying shell bank facies of unit II, were not observed in this newly discovered part of the La Meseta Formation.

We were also able to demonstrate that the sequence across Cross Valley was nearly continuous, not cut by a series of large faults as previously thought (Elliot et al. 1975). Several small faults were observed, but none had any significant displacement.

Figure 1. View looking south across Cross Valley-La Meseta Formation (LM); Cross Valley Formation (CV); Marambio Group (K). The light color of the sediments of the La Meseta Formation easily separates it from the Cross Valley Formation and the Upper Cretaceous Marambio Group.

Figure 2. View looking east along Cross Valley. Note the irregular trace of the contact of the La Meseta Formation (LM) with the Marambio Group (K) and the Cross Valley Formation (CV).

Exposure in the hills on the southern side of Cross Valley (figure 2) demonstrated clearly that the La Meseta Formation unconformably overlies the Lopez de Bertodano Formation (figure 3). It also appears that the La Meseta Formation and the Cross Valley Formation are unconformable; however, because of the shortness of the field season, the precise stratigraphic relationship between the two formations was not determined.

A detailed survey of the Cross Valley Formation vertebrate fossils makes it apparent that the formation was deposited in shallow marine conditions rather than in a terrestrial setting as previously thought (Elliot et al. 1975). Poorly preserved marine mollusks and fish debris were found throughout the formation. The presence of large quantities of coalified logs and plant debris together with marine fossils suggests that the Cross Valley Formation contains sediments deposited in extremely shallow marine conditions near the mouth of a river.

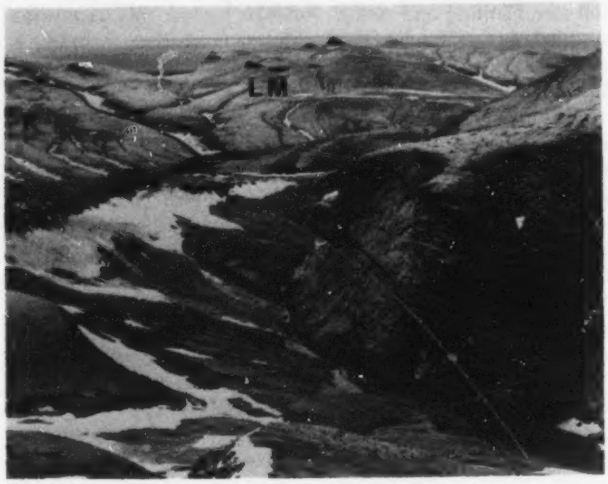

Figure 3. Contact between the La Meseta Formation and the underlying Upper Cretaceous Marambio Group (K).

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Land ice studies

Thermomechanical behavior of large ice masses: Ice-age causes and recent evolution of the antarctic ice sheet

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The growth and decay of large ice sheets is intimately tied to long-term variations in climate. For example, it has been suggested that surges of the antarctic ice sheet could cause the onset of ice ages (Wilson 1964). The formation of a huge ice shelf around the southern continent would increase the Earth's albedo, and the consequent global climatic cooling would lead to the inception of glaciation in the Northern Hemisphere. The surge also would produce a global rise in sea level, perhaps by as much as 15 to 20 meters (Hollin 1965). There is, in fact, isotopic evidence (Aharon, Chappell, and Compston 1980; Hollin 1980) of a rapid, though short-lived, rise in sea level by about 15 meters at the end of the last interglacial period, about 100,000 years ago.

We have explored, theoretically, the possibility that shear heating at the base of an ice sheet could be the physical mechanism responsible for catastrophic instability and surging of the ice mass (Schubert and Yuen 1982). This mechanism requires a climatically enhanced accumulation to increase the thickness of the east antarctic ice sheet above a critical value necessary for the onset of explosive creep instability. A rapid increase in ice thickness produces an immediate increase in the shear stress at the base of the ice sheet. The increased stress in the basal shear layer results in a sudden and large increase in the amount of frictional heating at the base of the ice sheet. This increased warming can lead to large-scale melting at the bottom of an ice sheet and surging of the mass.

We have estimated the critical thickness of the antarctic ice sheet by modeling the flow and temperature within the ice. In calculating the temperature, we account for vertical heat conduction through the ice, vertical advection of heat by the motion of the ice, and heat generated by friction. In computing the flow, we use a realistic creep law for ice, with strong temperature dependence and non-Newtonian stress dependence. We performed an extensive set of model calculations, varying such parameters as accumulation rate, surface slope, and activation energy of creep. All the results showed that the critical thicknesses needed to produce shear-heating instability are not much larger than the present value of the thickness of the antarctic ice dome.

The waxing and waning of ice sheets redistributes mass (water) on the Earth's surface and as a result causes changes in both the geographical location of the rotation pole and the length of the day. Observations of these changes (Dickman 1977; Lambeck 1980) can tell us about the Earth's interior (the viscosity of the mantle) and the history of the ice sheets. We attempted to learn from these changes by constructing layered, viscoelastic models of the Earth's interior and then comparing theoretical predictions of variations in the Earth's rotation produced by models of glaciation and deglaciation with observational data (Sabadini, Boschi, and Yuen 1982; Sabadini and Yuen in press; Sabadini, Yuen, and Boschi 1982a, 1982b; Yuen, Sabadini, and Boschi in press). We found that periodic forcing from the Cenozoic glaciation cycles can produce a net polar wander speed of 1 degree per 1 million years.

Such a secular trend in the motion of the rotation pole can have a profound influence on the future course of ice ages. The geographical distribution of oceans and continents must be optimal for the astronomical forcing mechanism (Milankovitch 1930) to produce periodic glaciations. However, this distribution cannot be maintained indefinitely in the presence of true polar wandering, and this may account for the termination of an ice-age epoch. The degeneracy of viscosity solutions in fitting the rotational data (Sabadini et al. 1982b) is removed by melting from the antarctic ice sheet since 18,000 years ago by an amount equivalent to a 25-meter rise in the eustatic sea level. This suggests that much larger ice shelves existed around Antarctica during the glacial maximum in the late Wisconsin than are present today.

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Dome C geophysical survey, 1981-1982

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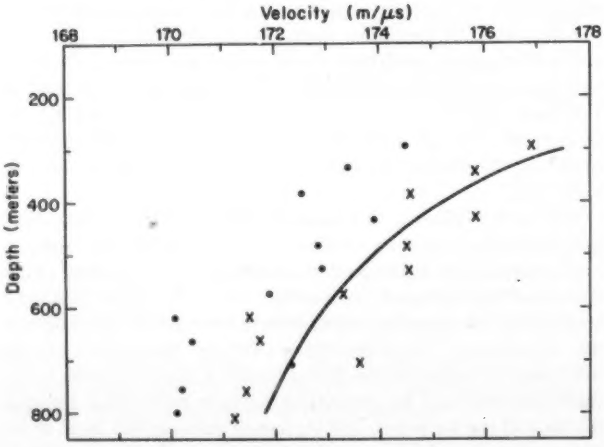
The geophysical survey at Dome C continued for a third season between late November 1981 and late January 1982. The measurement program was more specialized than in previous years (Bentley et al. 1979; Shabtaie et al. 1980), with concentration on measurements of electromagnetic wave velocity in the firn, sonic logging and seismic shooting in the 900-meter borehole (Lorius and Donnou 1978), a search for seismic reflectors deep within the ice sheet, and tests of new radar recording equipment developed at the University of Wisconsin. Some magnetic surveying and magnetotelluric recording also were carried out.

Radar studies. Two newly devised borehole experiments were carried out. In the first, a radar target was lowered into the 900-meter borehole and echo times from three surface sites to several depths within the hole were measured. The surface sites, each approximately 150 meters away from the borehole, were spaced around the hole at azimuths differing by about 120°. This arrangement permitted the separate calculation of the average vertical wave speed and the inclination of the borehole. In the second experiment, a half-wavelength dipole was suspended in a 100-meter borehole by a coaxial cable which was coupled directly into an oscillograph. Travel times from a transmitter on the surface to the antenna in the hole were used to calculate average wave speeds. The results of both experiments show good agreement with the borehole measurements carried out by Robin (1975) (figure).

Testing continued on digital recording for the radar system. The basic design (Bentley et al. 1979) is unchanged, but the system now includes a stacking circuit that can average and record 250 echoes every half second. Although digital recording on magnetic tape was not possible, the stacked records were displayed and recorded on a Honeywell 1865 oscillograph as a sequence of A-displays (displays showing signal amplitude as a function of time). Profiling was carried out along two 10-kilometer lines at a speed such that one display was recorded every 2 meters. The profiles showed internal reflectors whose amplitude changed rapidly in distances of only a few meters. Amplitude data on bottom and near-bottom echoes also were obtained.



Average vertical electromagnetic wave speed in the ice sheet above the indicated depth. Dots and crosses are lower and upper limits corresponding to reflection from the top and the bottom of the logger, respectively. The continuous line represents the average speed predicted by Robin's (1975) empirical equation relating wave speed and density. m/μs = meters per microsecond.

Several miscellaneous experiments were carried out. A transmit/receive switch was developed, but it provided only about 12 decibels of isolation and was abandoned. A 10-meter core was recovered and will be used for laboratory measurements of the permittivity of firn. Most important, some bench tests of the SPRI Mark II receiver unexpectedly revealed an amplitude-dependent signal delay. This delay, which may be as much as 0.20 microsecond, is a likely cause of the anomalously high average wave speeds often measured by the radar wide-angle technique (Jezek et al. 1978).

Sonic logging. A program of compressional wave (P) and shear wave (S) logging was carried out in the 900-meter borehole. The system (Bentley 1972) comprised a 28-kilohertz transmitter with two receiving transducers, either 2.6 or 10 meters apart, suspended below it. The section logged was between depths of 777 meters (limited by hole closure) and 137 meters (the top of the borehole fluid). Velocities were measured every 10 meters with the logger stationary, and every 0.2 meter with the logger in motion. For the latter measurements, the signals were recorded on the Honeywell oscillograph. Both P and S waves appear to be present. Preliminary analysis reveals no large velocity changes such as would be caused by a pronounced anisotropic crystalline fabric.

Borehole shooting. For comparison with the sonic logging, charges (0.15 kilogram) were detonated at five depths (600, 450, 350, 250, and 180 meters) in the borehole. An L-shaped recording spread with 24 geophones spaced at 30-meter intervals ("L-spread") was used. The seismograms obtained show good first breaks and should yield accurate determinations of the average vertical velocity in the upper ice sheet. Strong bottom reflections that should be useful for studying the ice-rock interface also were obtained.

Vertical reflection shooting. Reflection shooting concentrated primarily on a search for the deep intraglacial seismic reflectors that have been observed in West Antarctica (Bentley 1971) but never in East Antarctica. Approximately 20 analog and digital recordings were made on L-spreads at each of ten 30-meter shot holes. Indisputable reflectors located approximately 300 meters above the ice-rock interface were observed at two stations, and weaker probable reflections were observed at several others; all the data should be improved by digital signal processing. Evidence of a possible connection between the seismic reflector and the top of the basal no-reflecting zone widely observed from airborne radar studies will be sought.

Magnetic surveying. Eighteen new magnetic stations were occupied in the grid southwest portion of the local survey area in an effort to define more completely the high-gradient anomaly reported in Bentley and others (1981).

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French field activities at Dome C

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As part of the International Antarctic Glaciological Project (IAGP), glaciological investigations have been pursued in the Dome C (74°39'S 124°10'E) area during the past field seasons (Gillet and Rado 1979; Lorius 1975, 1980; Lorius and Donnou 1978).The work included shallow sampling and coring to a depth of about 900 meters. Studies of the samples made it possible to reconstruct recent and long-term (up to 30,000 years ago) changes of the Earth's atmospheric environment (climate, aerosols, atmospheric composition) and to evaluate the importance of global volcanic activity and pollution.

Particularly dramatic have been the changes associated with the transition from the last ice age (Wisconsin-Würm glaciation) to the Recent (Lorius et al. 1981). Drastic changes in carbon dioxide and in continental, marine, and cosmogenic aerosols associated with climate modification (temperature, precipitation, wind circulation) have been observed. The purposes of the

1981–82 fieldwork were to complement surface sampling, to retrieve ice samples left from previous drilling, and (mainly) to test a melting probe that would recover water instead of ice. The ultimate aim is to drill deep enough to study climate changes over the last climatic cycle (125,000 years). The Dome C site is particularly well suited for this purpose.

The probe (Gillet et al. 1982) is designed potentially to recover melted ice samples deeper than 3,000 meters. With an 8-meter-per-hour penetration rate in ice and runs up to 6 meters, it should be possible to drill to these depths during a summer season. The diameter of the borehole is about 55 millimeters; on each run, 12 liters of partly refrozen water are recovered in a 10-meter-long melt tank. Separation of water from the drilling fluid (DFA + Freon) is made by gravity. The drill has an outer diameter of 43 millimeters, is 15.6 meters long, and consists of five parts: hot-point, pump-and-flow measurement section, melt tank, 3.5-meter-long electronic section, and suspension and anchoring section. The cable weighs 1,200 kilograms. Two 0.93-square-millimeter conductors and the steel outer armor conduct a 7-ampere current which provides 2,240 watts at 320 volts on the tip. The surface voltage is about 900 volts. Two other conductors of 0.34 square millimeter allow us to measure flow, water level in the tank, and suspension and also set off an alarm when the tank is full.

The five-member team (F. Gillet, P. Laffont, M. Maccagnan, G. Marec, and C. Rado) arrived at Dome C on 5 December 1981 with 10,500 kilograms of equipment: electromechanical drill (600 kilograms), climatopic thermal probe (6,600 kilograms), drilling fluid and alcohol (2,000 kilograms), and insulated boxes for ice cores stored there (1,300 kilograms). It took a few days to set up the drill and to put a 130-meter polyethylene casing in the 180-meter-deep hole drilled in 1979. Since it was the first test in the field, we spent a few more days checking all equipment.

We started drilling on 17 December 1981 and stopped on 18 January 1982, leaving Dome C a week later. The drilling was limited to a depth of 235 meters. For the first 28 meters the penetration rate reached 5 meters per hour, a rate lower than that obtained in laboratory tests (8 meters per hour); the discrepancy may be attributable to impurities associated mainly with the casing. The length of the runs reached 4.6 meters. Drilling from 208 to 217 meters became more and more difficult because of the increasing friction of the drill against the wall. We explain this abnormal friction as being due to a permanent deformation of the stainless steel melt tanks, the yield point of these tubes not being great enough. Continuing at a slower penetration rate (1.5–2 meters per hour) and with shorter runs (1.5 meters), we were able to ream the hole to 235 meters before we had to pack the equipment for retrograding at the end of the season.

After this first field test we can say that the principle of the thermal probe seems satisfactory. Most of the technical problems encountered (mainly involving hot points, the pump, flow measurement, and the heating of pipes) were solved. Only the problem of friction of the drill against the wall made it impossible to go deeper than 235 meters within the available time. We plan to solve this problem by using a new material for the tank and also by setting the suspension under the electronic section with an articulation point. We believe that with these modifications and some other minor adjustments we will be able to drill more than 2,000 meters in a single summer season.

The National Science Foundation provided logistical support for this project, and it was carried out with the help of Expeditions Polaires Françaises through grants from Terres Australes et Antarctiques Françaises et Centre National de la Recherche Scientifique.

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Ross Ice Shelf and Dome C oxygen-isotope analysis

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A triple-collector mass spectrometer, Micromass 903, with an online carbon dioxide (CO_2) equilibration system, Micromass 5020, for oxygen-isotope analysis, was installed in the Quaternary Isotope Laboratory in 1979. Both units are automated and controlled by computer. The system has been calibrated with International Atomic Energy Agency standards, and it is linear and correct over the range 0‰ to −55.5‰ [that is, V-SMOW (Vienna-Standard Mean Ocean Water) to SLAP (Standard Light Antarctic Precipitation)]. Precision of sample preparation and mass spectrometric measurement, as derived from repeated sample preparations, is 0.1‰ for water samples. The system is used for studies of oxygen isotopes in antarctic ice.

In the 1978–79 field season, the Soviet Antarctic Expedition and the U.S. Antarctic Research Program obtained a 416-meter-long, 8-centimeter-in-diameter core through the Ross Ice Shelf at site J-9 (82°22'S 168°40'W) (Zotikov, Zagorodnov, and Raikovsky 1979). In May 1981, a first set of 40 samples to be used in

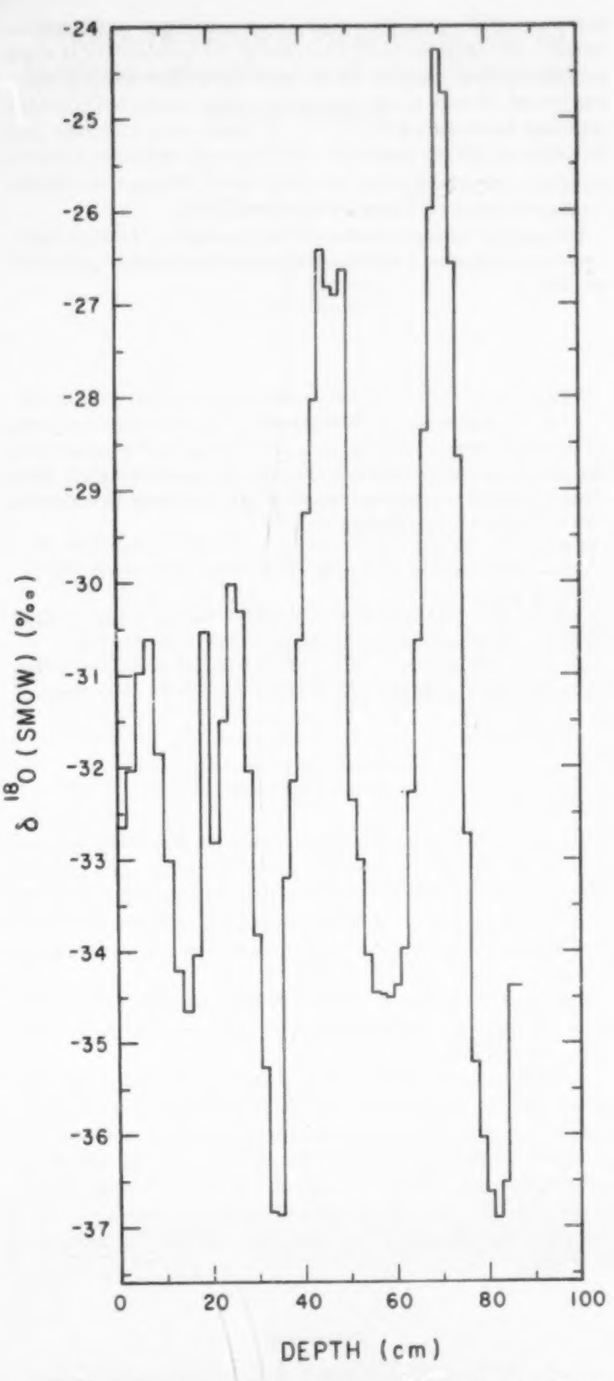

Figure 1. Short-term $\delta^{18}O$ (oxygen-isotope composition) variations in the Ross Ice Shelf at site J-9: core 132, drilling section 79 (depth, 101.88–102.95 meters). SMOW = Standard Mean Ocean Water.

measuring $\delta^{18}O$ (oxygen-isotope composition) was cut from this core at the Central Ice Storage Facility in Buffalo, New York. In addition, samples were obtained from 39 core sections sampled and split for microparticle analysis by L. G. Thompson of Ohio State University.

Measurements are still in progress, but some general trends emerge. The first section available at 35 meters deep has a $\delta^{18}O$ of about −28‰ relative to the SMOW standard. With increasing depth the ice gradually gets lighter, measuring about −35‰ at 250 meters. Between about 270 and 290 meters, the $\delta^{18}O$ values drop abruptly from −37‰ to −42‰. From this depth downward to the end of the available core at 410 meters (freshwater ice/sea-ice boundary), the ice has a $\delta^{18}O$ of about −42‰. Superimposed on this long-term trend are $\delta^{18}O$ variations with shorter periodicities. Down to 100 meters, cyclic short-term variations in $\delta^{18}O$ are absent. At about 100 meters, variations in $\delta^{18}O$ of up to 12‰ occur with a layer thickness of about 20 centimeters. Although this type of cyclic $\delta^{18}O$ variation is not found in all of the deeper sampled sections, they are present in several of them. The layer thickness over which these large-amplitude oscillations are observed decreases with increasing depth to 6–7 centimeters at 300 meters depth. The amplitude decreases over the same interval to 2–3‰. Examples are shown in figures 1, 2, and 3.

The annual accumulation of atmospheric precipitation at J-9 is about 90 millimeters of water equivalent, having a $\delta^{18}O$ of −29.4‰ (Clausen et al. 1979). Therefore, an annual-layer thickness of about 30 centimeters can be expected near the surface. The annual-layer thickness decreases rapidly with depth due to compaction and flow thinning. Measurements of sodium (Na) concentrations at a depth of about 66 meters indicate a layer thickness of about 5 centimeters (Herron and Langway 1979). Continued thinning will lead to an annual-layer thickness of about 2 centimeters at 100 meters depth. The layer thickness of the short-term $\delta^{18}O$ variations observed below 100 meters is 5 to 10 times greater. Therefore, these oscillations may not be of seasonal origin. Further study of the J-9 ice core, especially of medium- and longer term $\delta^{18}O$ variations, is in progress. The remaining core sections will be sampled in such a way that the strong short-term $\delta^{18}O$ fluctuations will average out.

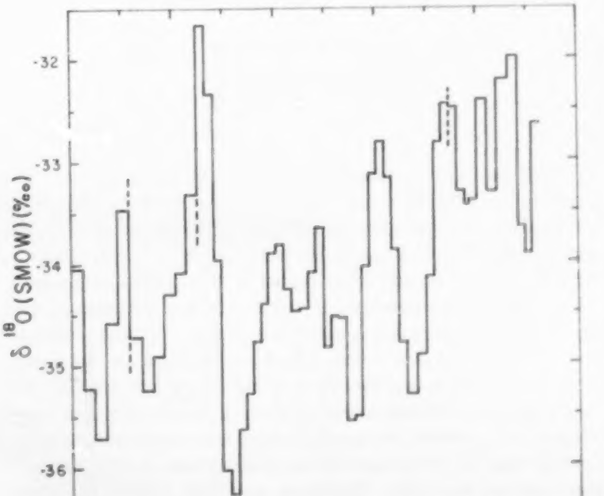

Figure 2. Short-term $\delta^{18}O$ (oxygen-isotope composition) variations in J-9 core 132, drilling section 186 (depth, 212.82–214.00 meters).

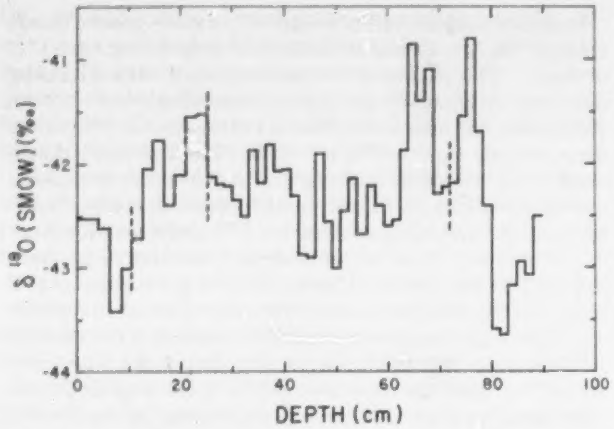

Figure 3. Short-term $\delta^{18}O$ (oxygen-isotope composition) variations in J-9 core 132, drilling section 262 (depth 292.16–293.16 meters).

A second study involved surface-snow samples from the Dome C area. During the 1978–79 field season, I. M. Whillans and J. M. Palais of Ohio State University collected snow samples from several pits in the Dome C area to study snow stratigraphy and a possible correlation with oxygen-isotopic composition. About 1,300 samples were analyzed at the Quaternary Isotope Laboratory. No clear correlation between $\delta^{18}O$ and stratigraphy was found. Moreover, the dissimilar nature of the $\delta^{18}O$ profiles obtained from different pits in the same area indicates that variations in $\delta^{18}O$ in the profile are not purely seasonal, but also represent reworking of the snow by wind. This agrees with the results reported by Benoist and others (1982).

The oxygen-isotope research at the Quaternary Isotope Laboratory was supported by National Science Foundation grant DPP 80-19756.

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Glaciology at Dome C and in the Allan Hills

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Ohio State University (OSU) completed its fieldwork at Dome C during the 1981–82 season with remeasurement of the strain network and temperature profiles and further studies on firn stratigraphy. The field team (the authors plus P. Torres) was in the field from the end of November to the middle of January.

We have been interested in the processes influencing firn structure and stratigraphy near the surface. Special attention has been given to determining if annual features can be recognized and to resolving the origin of highly porous, friable, and coarse-grained firn layers above 2 meters. Suspecting that vapor transfer is important, we studied short-term temperature variations to look for the effects of forced advection. Continuing the work started by Palais, Whillans, and Bull (1982) and Alley, Bolzan, and Whillans (1982), careful pit-wall studies were made and plastic-saturated samples were gathered for thin-section analysis. Oxygen-isotopic ratio measurements are being made by Pieter Grootes and Minze Stuiver of the University of Washington.

Samples to be used to measure gross-beta (β) activity in order to determine accumulation rates were collected at sites 100 kilometers from the Dome C camp in each of four directions. We plan to compare these accumulation rates with the depths of traceable radar reflecting layers, as has been done near Byrd Station (Whillans 1976).

Further measurements of the thermal properties of firn samples (Ewing et al. 1982) were made, and temperature profiles were remeasured.

I. Whillans spent 10 days with W. A. Cassidy's party near the Allan Hills (down-glacier to the east from Dome C; see Cassidy, *Antarctic Journal*, this issue). Steady-state calculations can explain the meteorite concentrations and the terrestrial ages of the meteorites found there. Fieldwork involved looking for evidence of folding or over-thrusting; none was found, and thus the ice in the ablation zone may be in stratigraphic order and very old.

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Photogrammetric determination of surface velocities and elevations on Byrd Glacier

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Surface velocities and elevations of Byrd Glacier (80°S 160°E) have been determined by photogrammetric methods from two sets of aerial photography obtained on 6 December 1978 and 31 January 1979. Terence Hughes (University of Maine at Orono) will use these photographs to study the glacier's dynamics and equilibrium. Natural features, which are present in virtually unlimited number on the glacier surface, were identified and marked with a point transfer device on both sets of photographs for use as motion markers. Many fixed points on rock at the glacier's lateral margins were identified and marked in the same way. Thirteen points on the perimeter of the area, established by ground survey to serve as control points, were targeted prior to photography. All these points were measured on the photographs by stereo comparator, and their elevations and positions were determined analytically by a rigorous least-squares adjustment of the two blocks of photographs simultaneously. The solution yielded coordinates of 1,467 terrain points from 6,738 image points (13,476 photo-coordinate measurements) on 322 photographs. Surface velocities of 601 common moving points, of which 472 are on the main ice stream, were determined from the differences in positions over the 56-day interval between photo flights.

The standard deviation of the photo-coordinate measurements is 16.3 micrometers, which is equivalent to 0.8 meter in

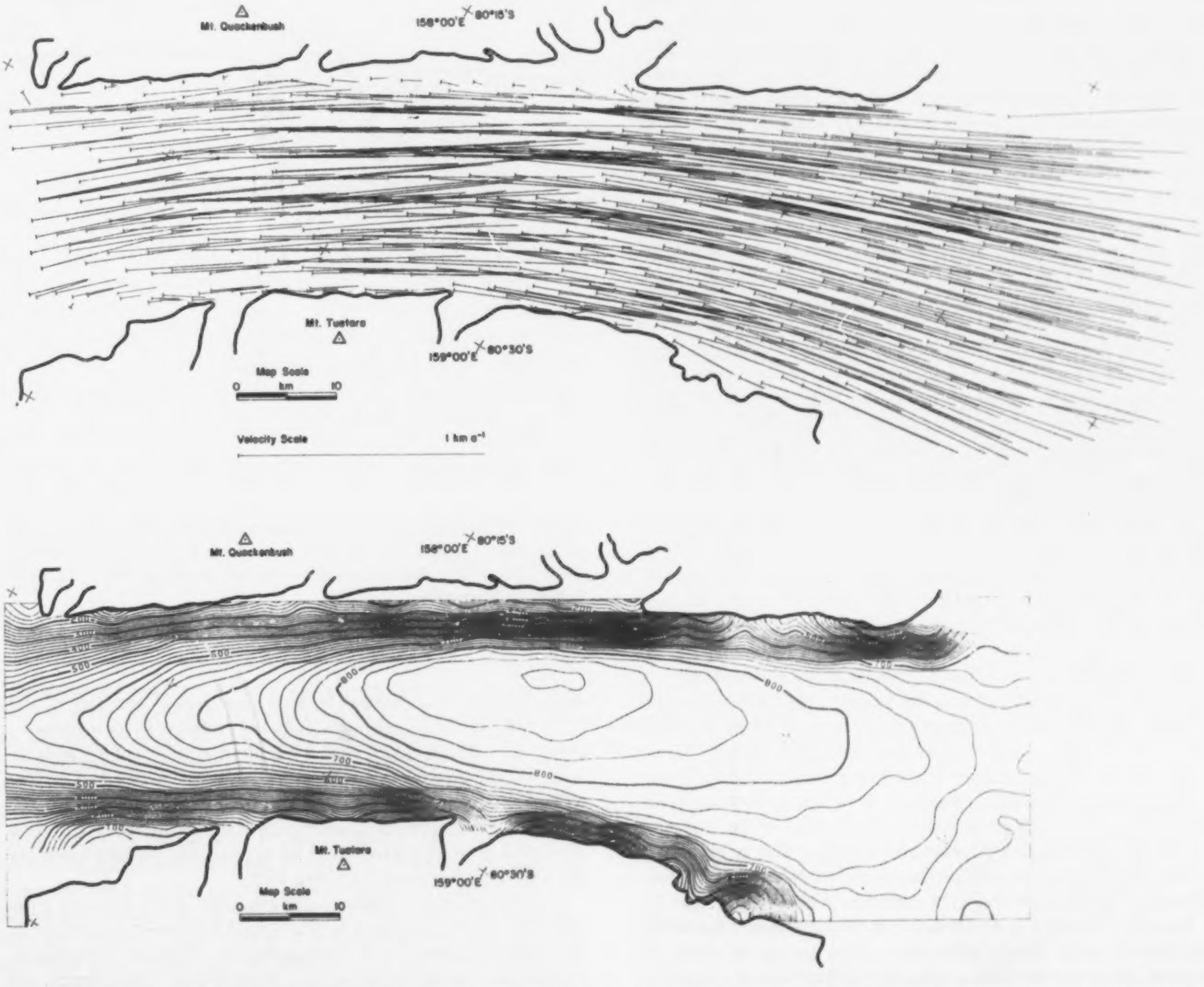

Figure 1. Surface velocity vectors and contours for Byrd Glacier. Velocity vector scale is given in the figure. Contours are in meters per year; contour interval = 20 meters per year.

planimetry and 1.8 meters in elevation at the average scale of the photographs. This appears to be a reasonable indication of the precision of the photogrammetric work. Redundancy of measurements is more than twice as large as in usual practice; photo residuals approximate a normal distribution very well and only 154 (1.1 percent) residuals are larger than three standard deviations. It is difficult to give a satisfactory estimate of accuracy, however, because no unambiguous checks are available. From various indirect approaches it appears that both planimetry and elevation are accurate to a few meters. Taking 5 meters as a reasonable, conservative numerical value yields errors of about 5 percent for the highest velocities and up to 15 percent and more for the low velocities near the glacier edge.

The results for the main ice stream are presented in figure 1 (page 79) as velocity vectors and as contours of constant velocity. The vector plot shows the distribution of measurements (the average spacing between points is about 2.5 kilometers) and the directions of motion, while the contour plot gives a much clearer indication of the velocity variation over the glacier. Among other things, it clearly shows that the dynamic centerline is displaced appreciably from the geometric centerline over about two-thirds of the glacier's length and that the maximum velocity of 875 occurs well upstream of the glacier mouth.

Velocities in this work agree very well with those reported by Swithinbank for a transect across the mouth of the glacier over a 348-day period during the years 1960–62. Values taken from a graphical profile (published at a larger scale as figure 3 in Swithinbank 1964) and one numerical value given for "middle of glacier" with probable error of 1 percent (Swithinbank 1963) agree with the values presented here within better than 3 percent over virtually the whole transect. Where direct comparisons are possible with independently determined velocities from ground surveys in 1978–79 (Hughes and Fastook 1981), all agree within 4 pecent, and the vast majority within 2 percent.

While carrying out the velocity measurements described, I noted that comparison of elevations obtained by ground surveys in 1978–79 with U.S. Geological Survey topographic maps made from 1960–62 aerial photography indicated a very large apparent lowering of the glacier surface in this short time interval. The apparent lowering varied between 50 and 150 meters along a 60-kilometer section of the glacier for which data were available (Brecher 1980).

To determine if the lowering was real, it was necessary to obtain more accurate glacier-surface elevations for 1960–62 than those that could be determined from the maps. Photogrammetric strip triangulations of three individual strips of photography (two taken in November 1960 and the third in February 1963), which cover the region of the greatest apparent lowering, have been completed. The old strips were oriented to fixed points on the margins of the glacier derived for this purpose from the 1978–79 photogrammetric work, thus bringing the measurements from the old and new photography into a common coordinate system. The comparison of surface elevations for the two epochs is presented in figure 2. Contours from the 6 December 1978 photography are shown at the top, and those from the earlier photography below. The points from which the latter contours have been constructed are indicated. (Density of points for the 1978 contours is shown in figure 1.)

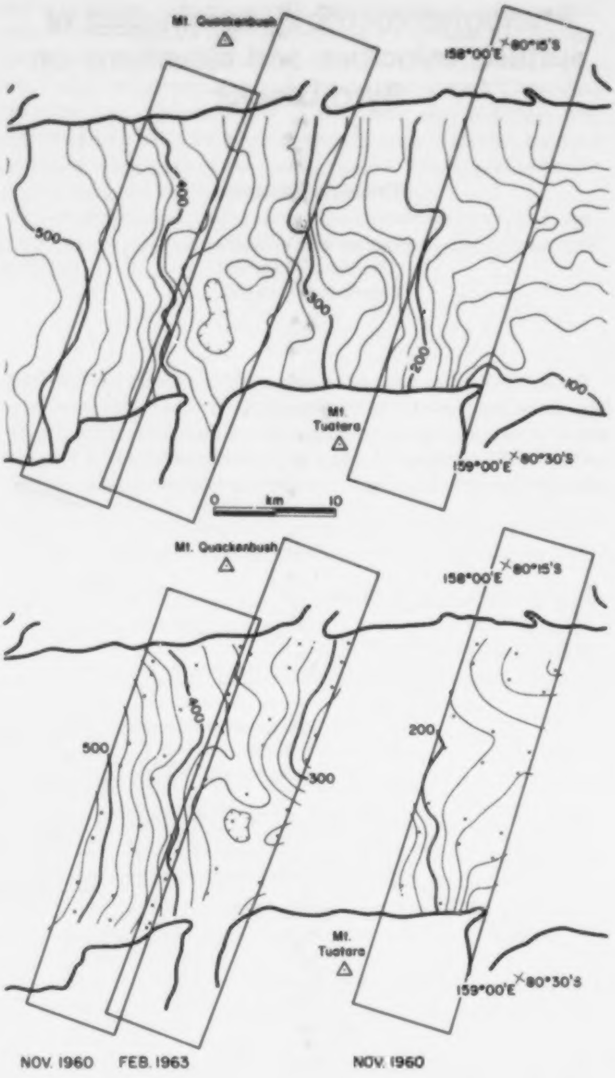

Figure 2. Elevation contours of a portion of Byrd Glacier from aerial photography in summer 1978–79 (top) and in summers 1960–61 and 1962–63 (bottom). Elevations are in meters above sea level; contour interval = 20 meters.

Except for some 2 to 3 kilometers at the upstream edge of the uppermost strip, where elevations differ by up to about 20 meters, there are no readily apparent differences in elevation. In fact, the spot elevations from the three strips fit so well with those from the 1978 block that they are generally indistinguishable. Although it is difficult to give measures of accuracy of the results, since no independent data are available for comparison, internal evidence (such as the excellent agreement betwen results in the overlap of two independently measured strips) indicates that accuracy higher than the expected 10 meters has been achieved in the measurements of the old strips. It can thus be stated unambiguously that no appreciable surface lowering has occurred between 1960 and 1978.

Lloyd Herd generously made available much time on photogrammetric equipment in the Aerial Engineering Section of the Ohio Department of Transportation; Norman Henderson, Henderson Aerial Surveys, Inc. (Columbus, Ohio) freely put his zoom point transfer equipment at my disposal; the Ohio State University Department of Geodetic Science provided time on stereo comparators; and the OSU Instruction and Research Computer Center provided computer time and facilities. Steven Johnson of Virginia Polytechnic Institute and State University made available his block adjustment program. Neil O'Brien did the point transfer work. Robert Tope drafted the figures.

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Isotopic studies of ice samples from the Allan Hills meteorite site

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Smithsonian Astrophysical Observatory researchers are continuing to investigate the gas in the ice at the Allan Hills meteorite collection site (76°45'S 159°00'E) (Cassidy, Olsen, and Yanai 1977). The terrestrial ages of the Allan Hills meteorites range from 11,000 to 700,000 years (Fireman 1980; Nishiizumi and Arnold 1980). Our primary effort is carbon-14 dating the carbon dioxide (CO_2) in the gas; however, we also measure the oxygen (O_2), nitrogen (N_2), and argon (Ar) abundances and isotopic compositions in the gas and the oxygen-18/oxygen-16 ($^{18}O/^{16}O$) ratio in the ice for more complete information. Gas is extracted from large (6 to 31 kilograms) samples by helium purging to obtain sufficient CO_2 for carbon-14 measurements with low-level proportional minicounters and Van de Graaff accelerators. Our gas extraction and counting systems have been described elsewhere (Fireman 1980; Fireman and Norris 1981). The accelerator method requires the conversion of CO_2 to solid carbon. The Van de Graaff accelerator dating has been accomplished with meteoritic CO_2 samples larger than 3 cubic centimeters STP (standard temperature and pressure) (Fireman et al. 1982) but not yet with the smaller CO_2 samples from ice. The counter and accelerator carbon-14 data are in accord; however, the accelerator method gives better statistical accuracy in 3 hours than can be obtained by 3 months of counting.

The figure, a map of the Allan Hills site (Nishio and Annexstad 1980), shows the locations of our samples relative to meteorite locations (dots) and a numbered stake network.

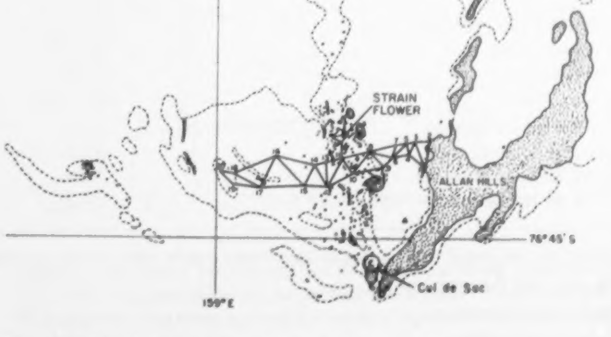
Table 1 gives the amount of gas extracted, the percentage of CO_2 in the gas, the specific activity of the CO_2, and the carbon-14 age obtained from the specific activity relative to contemporary radiocarbon. The percentage of CO_2 in gas from subsurface ice samples ranged from 0.030 to 0.065 percent, and the specific activities were below that of contemporary radiocarbon; therefore, ages greater than approximately 5,000 years resulted. The percentages of CO_2 in gas from surface ice samples were much higher, 0.187 and 0.129 percent, and the specific activities were three times that of contemporary radiocarbon. Two possible causes of the anomalously large specific activity in surface samples are (1) carbon-14 in nuclear fallout, which exchanged with the CO_2, and (2) carbon-14 produced by cosmic-ray spallation of ice, which exchanged with the CO_2.

Table 2 gives the variation of oxygen-18 ($\delta^{18}O$) values for the ice and for the oxygen in the gas, calculated by the equation

$$\delta^{18}O = \frac{(^{18}O/^{16}O_{\text{sample}} - (^{18}O/^{16}O)_{\text{SMOW}}}{(^{18}O/^{16}O)_{\text{SMOW}}} \times 1{,}000,$$

where SMOW is standard mean ocean water. The $\delta^{18}O$ of the oxygen in the gas was the same as that for the atmospheric oxygen samples and differed markedly for the $\delta^{18}O$ ice values. This result shows that the $^{18}O/^{16}O$ in atmospheric oxygen has been constant over a time that corresponds to the age of Allan Hills ice.

This $\delta^{18}O$ of the ice gives information on its source region. The Allan Hills meteorite site is in the catchment area of the vast Taylor Glacier, which extends over a 1-million-square-kilometer area. Drewry (1980) studied the motion of the Taylor Glacier and measured the $\delta^{18}O$ for ice at a few Taylor Glacier locations. His



Map of Allan Hills meteorite collection site.

Table 1. Amounts of gas, percentage of CO_2 in the gas, specific activity of the CO_2, and ^{14}C ages

Sample location, depth, and weight	Extraction temperature and pH[a]	Gas (cm^3 STP/kg[b])	CO_2 (percent)	$^{14}C/CO_2$ (10^{-3} dpm/cm^3)[c]	^{14}C age (1,000 years)
Frozen Water (7.8 kg)	24°C, 7.0 55°C, 1	20.4 0.4	1.35 N.D.[d]	9.0± 0.5	0 ± 0.7
1.0 cm^3 CO_2 (in purged Strain Flower Ice)	24°C, 1	N.D.	N.D.	<1.5	>12.0
590 cm^3 Air (in purged Strain Flower Ice)	24°C, 1	72.0	0.037	N.D.	N.D.
Allan Hills					
Stake 12 (surface) (31 kg)	24°C, 5.5 55°C, 1	47.0 0.9	0.187	27 ± 3	N.D.
Stake 12 (5–20 cm) (6.9 kg)	24°C, 1	53.9	0.030	≤4.0	≥5.0
Stake 18 (surface) (16.6 kg)	24°C, 5.5 55°C, 1	20.1 0.4	0.129	25 ± 6	N.D.
Stake 14 (5–20 cm) (5.75 kg)	24°C, 1	55.5	0.034	≤4.0	≥5.0
Stake 14 (20–35 cm) (5.90 kg)	24°C, 1	66.9	0.033	N.D.	N.D.
Stake 10–11 (5–25 cm) (12.9 kg)	24°C, 5.5 55°C, 1	46.0 1.5	0.054	3.9 ± 1.9	2.7–11.5
Strain Flower (5–25 cm) (10.3 kg)	24°C, 1	52.5	0.047	4.3 ± 1.8	2.3–9.7
Center Strain Flower (5–25 cm) (14.46 kg)	24°C, 1	35.5	0.058	5.0 ± 1.5	1.8–7.5
Cul de Sac (5–20 cm) (17.1 kg)	24°C, 1	41.6	0.065	≤2.3	>10.0
Cul de Sac (20–35 cm) (8.0 kg)	24°C, 1	50.5	0.051		

[a] pH = hydrogen-ion concentration.

[b] cm^3 STP/kg = cubic centimeters (standard temperature and pressure) per kilogram.

[c] 10^{-3} dpm/cm^3 = 0.001 decay per minute per cubic centimeter.

[d] N.D. = not determined.

Table 2. Ice and gas (oxygen) $\delta^{18}O$ values at Allan Hills and for atmospheric samples

Location	Depth	$\delta^{18}O_{ice}$ (‰)[a]	$\delta^{18}O_{gas}$ (‰)[a]
Allan Hills			
Stake 12	surface chips	−39.54 ± 0.35	N.D.[b]
Stake 12	5–20 cm	−39.23 ± 0.24	−21.80 ± 0.50
Stake 18	surface chips	−40.07 ± 0.20	−21.64 ± 0.25
Stake 14	5–20 cm	−41.39 ± 0.39	−23.50 ± 0.50
Stake 14	20–35 cm	−40.51 ± 0.47	−23.50 ± 0.50
Stake 10–11	5–20 cm	−43.48 ± 0.43	−22.16 ± 0.30
Strain Flower (center)	10–30 cm	−42.11 ± 0.50	−22.76 ± 0.30
Strain Flower	10–30 cm	−42.62 ± 0.10	−22.54 ± 0.30
Cul de Sac	5–20 cm	−40.74 ± 0.10	−21.23 ± 0.20
Cul de Sac	20–35 cm	−41.80 ± 0.60	−20.92 ± 0.21
South Pole air 383–79	N.A.[c]	N.A.	−22.30 ± 0.30
South Pole air 378–79	N.A.	N.A.	−23.13 ± 0.30
Local air (unprocessed)	N.A.	N.A.	−22.50 ± 0.30
Local air (processed through purged A.H.[d])	N.A.	N.A.	−22.62 ± 0.30

[a] Parts per thousand relative to standard mean ocean water. Errors estimated from reproducibility of δ on aliquots.

[b] N.D. = not determined.

[c] N.A. = not applicable.

[d] A.H. = Allan Hills.

values of −41.6 and 42.8‰ for the lowermost ice at Taylor Glacier snout (77°43.6′S 162°16.5′E) are identical to our values at stake 14 and in the Strain Flower and Cul de Sac regions. His value of −43.4‰ for the Taylor Glacier dome (77°44′S 158°22′E) is essentially identical to our value between stakes 10 and 11. These locations in the Taylor Glacier are possible source regions for the Allan Hills samples. On the other hand, Dome C (74°39′S 124°10′E), with a $\delta^{18}O$ of −50‰, is an unlikely source. The Allan Hills samples from stake 12 require a slightly warmer source than those investigated by Drewry (1980).

The O_2, N_2, and Ar abundances and the nitrogen-15/nitrogen-14 ($^{15}N/^{14}N$) and argon-40/argon-36 ($^{40}Ar/^{36}Ar$) ratios in the trapped gas are similar to those in contemporary air, except for positive $^{15}N/^{14}N$ ratios in a few samples.

I thank J. C. DeFelice for his help in all phases of this work, W.A. Cassidy and J. O. Annexstad for the Allan Hills ice, C. C. Langway, Jr. for the Byrd core ice, and W. Komhyr for the antarctic air samples. This research was supported by National Science Foundation grant DPP 78–05730.

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Microparticle concentration and size-distribution determinations from the J-9 core, Ross Ice Shelf

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In 1977–78 a 416-meter core was drilled through the Ross Ice Shelf at site J-9 (82°22.5′S 168°40′W) (Zotikov, Zagorodnov, and Raikovsky 1979). Preliminary examination of the core revealed a three-layer structure at the site (Zotikov 1979): a snow and firn layer extending from the surface to about 40 meters, a homogeneous bubbly ice layer extending to 410 meters, and a 6-meter-thick bottom layer thought to be old sea ice.

Recently, 39 1-meter sections of the core were obtained for analysis of microparticle concentration and size distribution. The microparticle analyses were conducted under class-100 clean room conditions using the Coulter Technique (Thompson 1977). The 1,913 samples analyzed provide considerable detail about microparticle concentration variations in each core section. Figure 1 illustrates the average concentration of small particles (between 0.63 and 0.80 micrometer in diameter) and total particles (diameter ≥ 0.63 micrometer) in each of the 39 sections. The detail obtained in the microparticle stratigraphy is presented in figure 2.

The samples from the three sections between 36 and 44 meters were contaminated by drilling fluid. This was confirmed

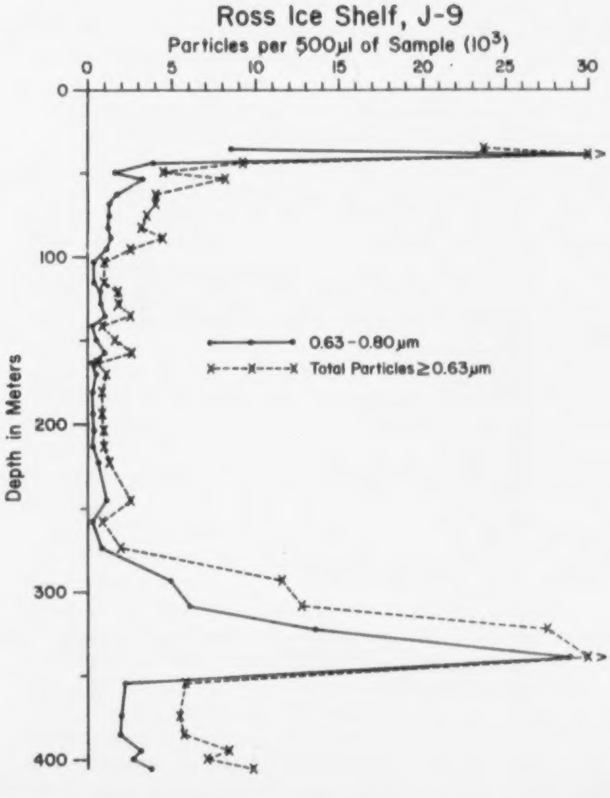

Figure 1. Average concentration of small particles (diameters 0.63–0.80 micrometer) and total particles (diameters ≥ 0.63 micrometer) per 500-microliter sample for each of the 39 sections from the Ross Ice Shelf J-9 core.

by microscopic examination of the particles. Pore close-off (density = 820 kilograms per cubic meter) was reached at 44 meters. Below pore close-off, ice samples are less subject to contamination and are easier to clean prior to analysis. The physical condition of the core sections analyzed ranged from good to excellent between 50 and 325 meters and from fair to poor below 325 meters. Below 325 meters, the sections were composed of numerous pieces, many of which were fractured. Thus, it was difficult to maintain very strict stratigraphic control, and larger samples were analyzed for these sections. Nevertheless, the average concentrations (figure 1) are unaffected by the fractures because the large ice fragments were easily cleaned.

Between 50 and 275 meters depth, particle concentrations are very low (figure 1), averaging approximately 5,000 particles (diameter ≥ 0.63 micrometer) per millimeter of liquid sample. These concentrations are very similar to the concentrations in the lower half of the core from site Q-13 on the Ross Ice Shelf (Mosley-Thompson and Thompson 1982). Below 275 meters, particle concentrations increase by a factor of 4 at 290 meters and by a factor of more than 10 at 340 meters. Below 350 meters, concentrations decrease to roughly 12,000 particles (diameter ≥ 0.63 micrometer) per milliliter of liquid sample, twice the concentrations between 50 and 275 meters. Figure 2 illustrates the concentration differences for two core sections.

Particle concentrations between 280 and 350 meters are similar to those found in the late glacial (late Wisconsin) ice in the Byrd Station deep core. The J-9 core is the fourth core to be analyzed which appears to contain ice deposited during the late Wisconsin as well as during the postglacial (Recent) period (Thompson 1977). Thompson and Mosley-Thompson (1981) report that such increases in microparticle concentrations were found to characterize late-glacial ice in three deep-ice cores—Byrd Station and Dome C cores from Antarctica and Camp Century core from Greenland. The particulate profile (figure 1) shows a very rapid drop in concentrations at 275 meters, similar to the rapid drop noted in the three deep cores discussed previously. The decrease in particle concentration can be attributed to either the rapid alteration in the net-accumulation regime diluting the particles or to a rapid depletion of the particle source. The rapid decrease in particle concentration at 350 meters is unusually sharp and does not appear in the other three deep cores previously discussed. The reason for the drop is unclear, but it may be related to the ice-flow regime at depth in the Ross Ice Shelf.

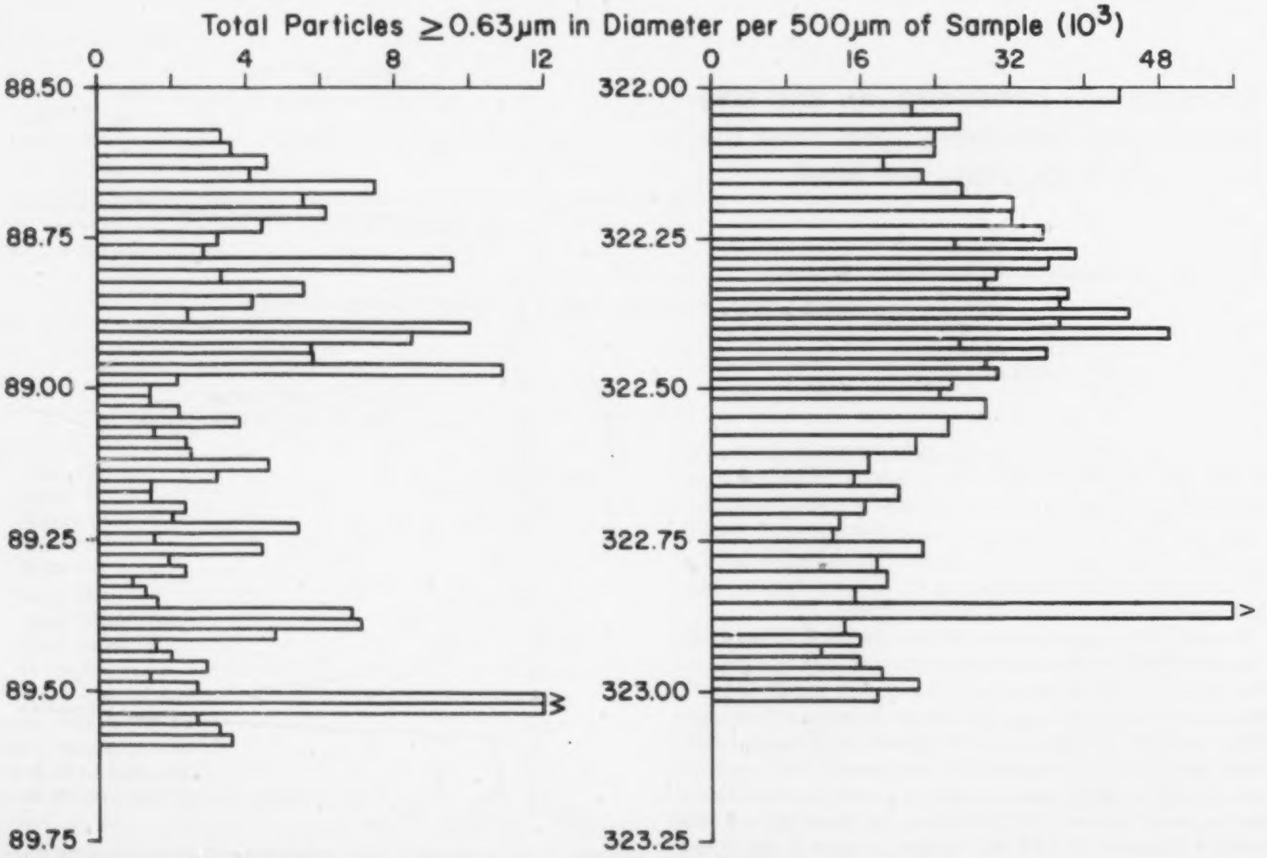

Figure 2. Total particle (diameter ≥ 0.63 micrometer) concentration in two sections from the J-9 core. The section on the left represents Recent ice, and the section on the right is believed to reflect ice deposited during the last glacial stage (late Wisconsin). Vertical axis gives depth in meters.

In conclusion, microparticle analysis of 39 sections of the 416-meter core from J-9 reveals a substantial increase in particle concentrations between 275 and 350 meters; the increase is believed to signal the presence of late Wisconsin ice from up the flow line in West Antarctica. In the near future, detailed oxygen-isotopic ratios ($\delta^{18}O$) will be available for many of the samples for which microparticle data are presented. The $\delta^{18}O$ results will reveal whether the lower third of the Ross Ice Shelf contains late-glacial ice. The oxygen-isotopic analyses are being conducted at the University of Washington.

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Intra-annual relationships between oxygen-isotopic composition of precipitation and temperature at the South Pole

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An understanding of the physical basis for the oxygen-isotopic composition ($\delta^{18}O$, or δ) of precipitation in central Antarctica is a prerequisite for confident interpretation of long-term δ-records derived from ice cores drilled in this area. Robin (1976, 1977) summarizes various lines of evidence which suggest, for recent millennia, that δ-values in antarctic precipitation are closely related to temperature. Jouzel and others (in press) have carried out a detailed comparison between the isotopic variations in firn samples from the South Pole and the corresponding *in situ* temperature data for the period 1957–78. The resulting statistically significant relationships demonstrate that stable isotopic ratios can be used to reconstruct some characteristics of the temperature regime prevailing at the time of precipitation. To provide a link between individual isotopic measurements in precipitation and the multiannual picture, and to get a more detailed idea of the governing physical mechanisms, the extensive set of δ-observations of south polar precipitation for the period November 1964 to October 1965 have been analyzed in greater detail than attempted by Aldaz and Deutsch (1967). Preliminary empirical results of this study are reported here and are contrasted with the conclusions reached by Bromwich and Weaver (in press) as to the seasonal behavior of the oxygen-isotopic composition in coastal precipitation. A limited comparison with the work of Jouzel and others (in press) also is included. Unfortunately, the 1964–65 interval considered here is poorly represented in their samples.

Aldaz and Deutsch's (1967) 89 observations of the oxygen-isotopic composition of freshly fallen snow were examined as monthly averages as well as individually. Because only the precipitation signal is of interest here, the accretion measurements are not included in the analysis. For the resulting sample sizes of 11 and 44, correlation coefficients (r) between δ and temperature must be at least 0.6 and at least 0.3, respectively, to be significantly different from zero with a confidence level of 95 percent. Corresponding values of the coefficient of determination (r^2) are 0.36 and 0.09.

Some of the results of the monthly analyses are given in table 1. The surface temperature at the time of sample collection ($\hat{T}^{\delta}$) has a closer relationship with $\hat{\delta}$ (monthly average of δ) than does the average surface temperture ($\hat{T}$). This result is in marked contrast to the situation at the coastal Syowa Station, where $\hat{T}^{\delta}$ and $\hat{\delta}$ are almost unrelated (Bromwich and Weaver in preparation). There is a weak increase in association between $\hat{\delta}$ and mean temperature with increasing height; the reverse applies for the δ-sampled precipitation temperature. Thus the best interpretation for $\hat{\delta}$ appears to be the monthly average of the simultaneous surface temperatures. This is also supported by scatter plots of the data. When temperatures above the surface are considered, both temperature variables appear, in general, to be correlated equally well with δ; however, consideration of nonlinear equations may reveal closer relationships between $\hat{T}^{\delta}$ and $\hat{\delta}$.

Another important result from the monthly analysis is that there is no significant lag between the mean temperature cycle and the δ-signal (table 2). In contrast, average coastal temperature leads the stable isotopic content of precipitation by about 1 month. This result is interpreted to mean that δ-values in coastal precipitation reflect the amount of sea ice to the north of Antarctica (Bromwich and Weaver in preparation). No such effect is apparent at the South Pole. The slight change with height of the relative phase of δ and temperature is consistent with the vertical variation of the annual temperature cycle above the South Pole; surface temperature changes slightly precede temperature changes aloft. A similar vertical phase variation occurs at Syowa Station (Weaver 1981).

To examine interseasonal changes, individual δ-observations are divided into two time groups: November to February values

Table 1. Results of the regression analysis on a monthly time scale between δ (dependent variable) and temperature at various levels in the atmosphere (independent variable)[a]

Level of temperature measurements (average height above surface)	(i)[b] r	r^{2d}	Slope ± 1 s.e. (‰ per 1°C)	Intercept ± 1 s.e. (‰)	(ii)[c] r	r^2	Slope	Intercept
Surface	0.78	0.61	0.35 ± 0.09	−33 ± 5	0.90	0.82	0.46 ± 0.07	−29 ± 3
650 millibars (340 meters)	0.82	0.67	0.76 ± 0.18	−22 ± 7	0.81	0.66	1.1 ± 0.3	−13 ± 9
600 millibars (890 meters)	0.85	0.72	1.3 ± 0.3	−4 ± 10	0.71	0.50	1.3 ± 0.5	−5 ± 15
500 millibars (2,140 meters)	0.85	0.72	1.5 ± 0.3	11 ± 13	0.79	0.62	1.5 ± 0.4	10 ± 16

[a] Mean temperatures were taken from Department of Commerce (1965, 1966).

[b] (i): Regression equation is $\hat{\delta} = A\hat{T} + B$, where $\hat{\delta}$ and $\hat{T}$ are the unweighted monthly averages of the δ-observations and of all temperature measurements, respectively. The caret indicates a monthly time average. A and B are the slope and intercept of the line. Based on 80 δ-observations.

[c] (ii): Regression is $\hat{\delta} = A\hat{T}^* + B$, where $\hat{T}^*$ is the monthly mean of the temperature observations at the time precipitation samples were collected for δ-determination. Because of missing temperature data, only 44 δ-values were considered.

[d] r^2 = coefficient of determination, fraction of the variance of the dependent variable explained by the regression equation.

Table 2. Coefficients of determination resulting from regression of $\hat{\delta}$ with the mean temperature at various levels as a function of lag. For a lag of +1, $\hat{\delta}$ is compared with T of the previous month.

Level	Lag in months between $\hat{\delta}$ and $\hat{T}$: −2	−1	0	+1	+2
Surface	0.14	0.51	0.61	0.52	0.13
650 millibars	0.27	0.62	0.67	0.41	0.10
600 millibars	0.37	0.66	0.72	0.38	0.08
500 millibars	0.38	0.62	0.72	0.35	0.07

represent conditions during the warm part of the year, and the March to October interval primarily monitors the polar night (compare Schwerdtfeger 1977). A slightly different annual breakdown was used by Jouzel and others (in press).

Table 3 shows that there is a pronounced seasonal variation in the δ-temperature relationship. For the November–February period, individual δ-values are unrelated to simultaneous temperatures at any level. In contrast, Jouzel and others (in press) found a fairly close connection over a 21-year period between isotopic maxima in the firn and corresponding mean temperatures (for December and January). These results are compatible if the individual warm-period δ-values reflect the prevailing temperature regime. During the colder part of the year, the

Table 3. Results of the regression analysis between individual δ-observations and simultaneous temperatures at different levels

Independent variable	November–February n	r^2	March–September n	r^2	Slope ± 1 s.e.	Intercept ± 1 s.e.	Entire year n	r^2	Slope	Intercept
T_s[b]	17	.06	27	.36	.38 ± .10	−34 ± 5	44	.64	.47 ± .05	−29 ± 2
T_{650}[c]	17	.07	27	.43	.57 ± .13	−33 ± 5	44	.47	.85 ± .14	−21 ± 5
T_{600}	17	.02	27	.60	.81 ± .13	−26 ± 5	44	.39	1.1 ± .2	−14 ± 7
T_{500}	17	.01	27	.54	.93 ± .17	−15 ± 7	44	.44	1.3 ± .2	1 ± 9
T_{MAX}[d]	10	.15	27	.62	.81 ± .13	−27 ± 4	37	.61	1.1 ± .1	−16 ± 5

[a] All data are from Aldaz and Deutsch (1967).

[b] T_s = surface temperature.

[c] T_{650} = temperature at the 650-millibar level.

[d] T_{MAX} = temperature at top of surface inversion (only assigned a value when a surface inversion was detected during a radiosonde ascent).

Table 4. Comparison of regression analyses between oxygen-isotopic ratio and temperature at various levels for winter conditions at the South Pole

Level	(i)[a]			(ii)[b]		
	r	r^2	Slope ± 1 s.e.	r	r^2	Slope ± 1 s.e.
Surface	0.06	0	0.14 ± 0.51	0.60	0.36	0.38 ± 0.10
650 millibars	0.31	0.10	0.44 ± 0.31	0.65	0.43	0.57 ± 0.13
600 millibars	0.37	0.14	1.0 ± 0.6	0.78	0.60	0.81 ± 0.13
500 millibars	0.38	0.14	1.2 ± 0.7	0.73	0.54	0.93 ± 0.17

[a] (i): Calculated from table 3 of Jouzel and others (in press); obtained from a 21-year time series of mean values.

[b] (ii): March-September results from table 3; obtained from individual observations of δ in precipitation and concurrent temperatures during one winter; n = 27.

association between δ and temperature increases with height above the surface (table 3). Jouzel and associates (in press) compared isotopic minima in the firn and mean April–September temperatures and obtained rather similar δ-temperature gradients, as summarized in table 4. These results for winter are consistent with the idea that the surface layer is largely separated from the free atmosphere where snow forms, by the strong low-level atmospheric stability (e.g., Jouzel et al. in press); this effect should be minimal during the warmer months, when the surface temperature inversion is much weaker (Schwerdtfeger 1970).

These seasonal differences disappear when monthly averages are considered. Therefore, the warm-period δ-values must be determined by general temperature conditions, as proposed previously; this is also suggested by scatter plots of the data. Comparison of tables 1 and 3 reveals that statistically indistinguishable results are obtained from both the (monthly) analysis of $\hat{\delta}$ versus $\hat{T}^s$ (table 1, ii) and from the individual δ-temperature comparison for the entire year. The notable difference is as expected, the decrease in the coefficients of determination accompanying the increase in sample size.

It should be noted that the regression equations obtained from comparison of δ and the 500-millibar temperature for the entire year (tables 1 and 3) are indistinguishable from the equation derived by Aldaz and Deutsch (1967):

$$\delta = 1.4t + 4.0,$$

which relates individual δ (in parts per thousand) observations in precipitation to the "effective condensation temperature" t (in °C). If precipitation is uniformly distributed throughout the year, insertion of the annual mean isotopic ratio in the equation will give a t value close to the annual mean 500-millibar temperature. Most likely this is the basis for Robin's (1977) conclusion that, on an annual time scale, the average temperature above the surface inversion is within 4°C of the effective condensation temperature.

The isotopic content of precipitation at the South Pole probably is determined by local moisture advection conditions, as monitored by $\hat{T}^s$. During the dark period, the moisture available for precipitation is tied closely to the temperature regime immediately above the surface inversion; this region is likely to be supersaturated with respect to ice (Miller and Schwerdtfeger 1972) and holds most of the atmosphere's water vapor. Around the time of the summar solstice, δ-values reflect the prevailing temperature conditions but are unrelated to the temperature variations accompanying precipitation. A physical explanation for this result is being sought.

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Nitrates in South Pole snow

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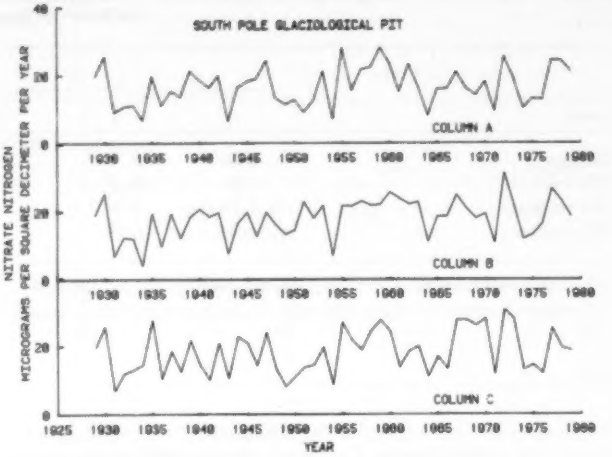

Annual nitrate concentrations at the South Pole, determined from three columns taken from the South Pole glaciological pit.

Most of our activities this past year have been directed toward completing analytical work and data reduction on firn cores and pit samples gathered in previous years. The most important results were obtained from a 10-meter-deep snowpit that was excavated near South Pole Station during the 1979–80 field season. More than 800 samples, collected from three columns down the pit walls and spaced roughly 1.5 meters apart, were analyzed for nitrate. The pit spans 51 years over the period 1929–79 and provides us with the first comprehensive statistical test of our analytical and sampling technique. The three sample sets are of such high resolution that they can serve as a basis for a quantitative test of the relatonship between solar activity and the nitrate concentration in the individual snow layers.

Absolute dating and the determination of annual snow accumulation was accomplished by counting and measuring the thickness between the individual depth hoar layers that form each year, at the end of the polar summer, directly below the snow surface (Giovinetto 1960). Among the three columns, the relative dates were established by tracing the depth hoar layers along the pit walls from one column to the next. Annual nitrate fallout (flux) at South Pole was calculated from the firn density, thickness, and nitrate concentration in each of the annual layers.

The figure shows the curves of flux variations through time for the three sample columns. Although the signal contains a substantial noise level, the curve's general shape is clearly recognizable in all three data sets and specific intervals of high- or low-nitrate flux are usually shared by all three. Intrinsic noise is contributed by natural processes, causing local variations in the accumulation and mixing on the snow surface, and by any redistribution of nitrate that may occur in the compaction and recrystallization process taking place as the snow is converted to firn. Extrinsic noise is derived from errors in measurement, collection, packaging, chemical analysis, and data transcription and analysis.

Cross correlations between the three columns vary between 0.73 and 0.80, indicating that total noise is not so large that it tends to obscure major features in the signal. Absent is any of the nitrate-spike component that had been reported in previous firn core studies (Parker and Zeller 1979; Parker, Zeller, and Gow in press; Parker et al. 1978; Rood et al. 1979; Zeller and Parker 1979, 1981a, 1981b). During analysis we found that anomalously high values were extremely rare, were usually confined to samples contained in bags that had broken in shipment, and were never repeated in the adjacent columns. Lack of nitrate spikes in our analyses has confirmed our growing suspicion that most, if not all, were artifacts of drilling and packaging procedures that introduced such high levels of contamination that the usual core cleaning methods were inadequate (Dreschhoff, Zeller, and Parker in press). The analytical data now available from this sample set are of significantly higher quality than any previously obtainable from firn cores. Clearly, this increase in quality is related to the large number of samples and to the high analytical precision and accuracy. We believe this test confirms the validity of our collecting and analytical procedures and establishes the reliability of the data for use in determining the quantitative relationship between solar activity and the nitrate concentration in the individual yearly snow layers.

Using this data set, Laird and others (in press) showed that there is a positive correlation between the nitrate flux and two recognized indices of solar activity, the Zurich sunspot numbers and the geomagnetic "aa" index. The correlation between the nitrate flux values in the snow at South Pole Station and the yearly "aa" index is 0.45 ($p < 0.005$). This implies that a substantial portion of the nitrate deposited in South Pole snow is derived from a solar-terrestrial mechanism, probably operating in the middle and upper atmospheres. Furthermore, since the best correlation is with essentially zero lag,* it appears that the time between nitrate formation and its ultimate deposition in the snow must be 6 months or less.

It is recognized that the geomagnetic index is only a secondary measure of variations in solar output. Clearly, a more rigorous test of the relationship between solar activity and nitrate flux would result if the primary source of the ionization responsible for nitrate production in the atmosphere could be determined. Fortunately, this will be possible because satellite data have been assembled in a continuous series for the last 20 years (Armstrong, Brungardt, and Meyer in press), and work is now in progress to determine the extent to which the nitrate flux measurements are reflecting the high-energy particle component of specific solar events. Future work will also be directed toward development of new analytical apparatus that can be operated in the field in Antarctica. Since this equipment requires much smaller samples, it will be possible to increase the resolution with which the yearly snow layers can be examined by a factor of at least five over that used in the study reported here. Such extremely high resolution sampling will permit the intrinsic errors to be quantified, and the capability for field operation should eliminate nearly all of the extrinsic errors.

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* Zero lag means the nitrate descends from the atmosphere very rapidly. There is no delay in the nitrate being incorporated into the snow.

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South Pole ice core drilling, 1981–1982

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A cooperative ice core drilling, core processing, and stratigraphic logging program was conducted at Amundsen-Scott South Pole Station during the 1981–82 season by investigators from the Polar Ice Coring Office (PICO), the national Hydrology Research Institute/Environment Canada (NHRI), and the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). A 202.4-meter ice core was collected, logged and packaged in the field, and then shipped to the CRREL ice core storage facility, where it will be made available to National Science Foundation-sponsored glaciologists for further analysis.

The principal objective of the field program was to collect a 200-meter core from the South Pole Station in order to extend the site's ice core chronology beyond the existing 115-meter depth. This was accomplished by using the Canadian Rufli-Rand electromechanical drill, which had been used in 1980 on Mount Logan (5,300 meters elevation) to collect ice cores to a maximum depth of 103 meters (Holdsworth in press). The drill's design is based on principles established by Rufli, Stauffer, and Oeschger (1976) and by Rand (1976). The drill collects a core 96–99 millimeters (3.8–3.9 inches) in diameter in runs averaging 1 meter in length. Unique to the Canadian drill system is a geodesic dome that serves as a structural unit supporting the central fixed tower and providing shelter for the drill crew. The entire packaged drill system, including winch platform, tower, drill, and shelter, weighs 730 kilograms (1,606 pounds).

The drill shelter, a core processing laboratory van, and PICO's 6.5-kilowatt generator were set up in the center of the station's taxiway oval (figure 1). A core storage trench (3 meters deep × 3 meters wide × 6.4 meters long) was excavated adjacent to the drill site. Drilling began on 17 December with a three-member drill crew and one core processor and continued for 22 days until drilling stopped at a depth of 202.4 meters. The average working day under normal conditions was 7.5 hours.

Initial problems with the antitorque spring-skate system and cutting bits were overcome as drilling progressed. During drilling runs in the upper 60 meters of the hole, the oversized antitorque system tended to jam in the hole, thereby reducing the penetration rate and causing a "stick-slip" motion as the drill

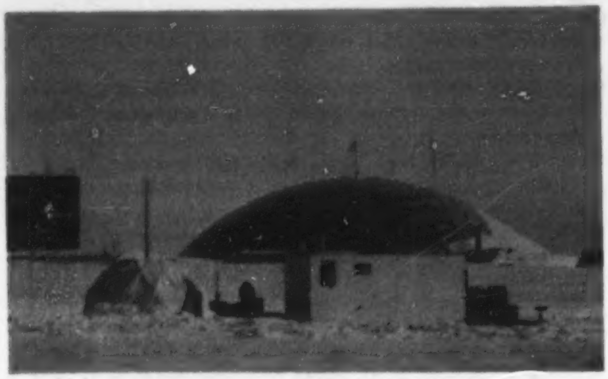

Figure 1. The drill shelter and laboratory van in the center of the taxiway oval at South Pole Station, January 1982. (Photo by B. Koci)

progressed down the hole. The cutters used were mainly those with a 15-degree clearance angle; this, coupled with reduced penetration rates, produced very fine chips. After installation of cutters that took bigger bites and addition of ice skates to the antitorque springs, drilling resumed, with the drill current increased slightly from the normal 1.0 ± 0.2 ampere to 2.0 amperes. Upon completion of one run and winching of the drill, it was apparent from cable-blistering at the sheave and tangling above the drill/cable termination that the antitorque section had failed to keep the drill from rotating downhole. As a result, approximately 62 meters of cable had to be cut off and the remaining 273 meters of cable reterminated. The antitorque system was completely reworked to eliminate jamming in the hole.

Normal drilling resumed on December 23 at a depth of 60 meters (with runs averaging 80–90 centimeters and turnaround times of 17.5 minutes) and continued to the firn/ice transition at approximately 115 meters. Below this depth, turnaround times increased to 20 minutes per run (5 minutes of actual drilling time) and core lengths were reduced to 70–80 centimeters.

At 127 meters, the cable was reterminated to correct a short circuit and the antitorque system was reworked. The increased hardness of the ice at this depth and the −51°C temperature dulled the cutter edges; the resulting fine ice chips were difficult to transport along the drill's auger flights. This made it necessary to sharpen the bits before each run. These problems contributed to gradually declining core production (5–8 meters per day) and to termination of drilling at 202.4 meters.

CRREL's contributions to this project were providing glaciological expertise, including measurements of the basic physical and structural properties of the cores, logging, and stratigraphic analysis, and packaging of the cores at the drill site, and furnishing refrigerated facilities for processing cores for analysis by NSF-approved investigators. All cores were successfully age-dated on the basis of well-preserved annual layering, using techniques previously applied with success by Giovinetto (1960) and by Gow (1965). This depth—202.4 meters—is the deepest at which visible stratigraphy has been successfully delineated in ice cores. The core is estimated to represent a record of snow accumulation extending back approximately 2,000 years. This attention to stratigraphy is needed to ensure that sampling of the cores for geochemical, microparticle, entrapped gas, and stable isotope records will be performed on the basis of natural stratigraphic breaks. In the past, much valuable information has been lost because of the failure of most investigators to recognize the importance of stratigraphy in the selection and preparation of their samples.

While at the drill site, A. J. Gow also initiated studies of the density, bubble patterns, and crystal dimensions of the cores. Preliminary measurements of density and load are presented in figure 2. The firn/ice transition occurs at a depth of approximatey 115 meters, the deepest ever recorded in Antarctica.

Upon completion of drilling, all cores were airlifted to McMurdo Station for subsequent transshipment to CRREL, where they will be processed for analysis by approved investigators.

In addition to work with the ice core, PICO team members collected three gas samples for the Physics Insitute, University of Bern, Switzerland. The samples were collected through a Teflon tube inserted in 1980–81 in a borehole to a depth of 40 meters below the surface. The University of Bern reports that all gas samples show atmospheric composition. Collection of air samples from the firn will be repeated during the 1982–83 field season. These gas content analyses are important with respect to the interpretation of data from gas analyses performed on old ice samples (Stauffer 1981).

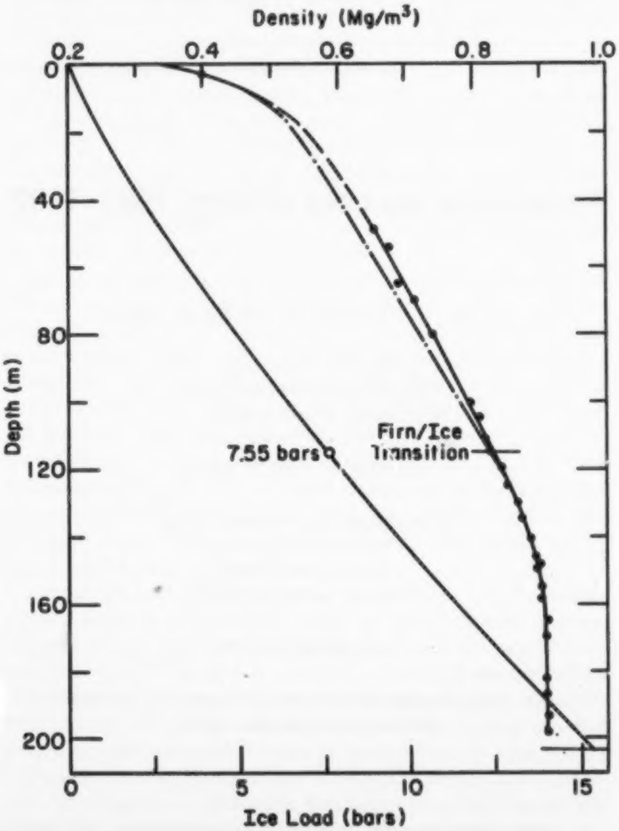

Figure 2. Density and ice-load profiles to 203 meters depth at the South Pole. Density curves obtained by Giovinetto (1960; dashed lines) and by Chiang and Langway (dashed-dotted lines) also are indicated. Density is measured in megagrams per cubic meter. (Figure by A. J. Gow)

PICO also prepared the Gearhardt-Owen logging winch (used previously in logging and sampling the Ross Ice Shelf Project access holes at J–9) for use by University of Wisconsin-Madison geophysicists in their sonic logging of the 900-meter borehole at Dome C.

The drill team consisted of G. Holdsworth, B. Koci, and K. Kuivinen; A. Gow performed the core logging and stratigraphy.

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Sea ice studies

Some applications of the McMurdo-generated NOAA satellite imagery for polar-ice research

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The establishment of a high-resolution picture transmission (HRPT) satellite data acquisition station at McMurdo (77°51'S 166°39'E) by the National Science Foundation has opened an excellent opportunity to use satellite information for antarctic research. A description of this system has been given by Wiesnet, Berg, and Rosenberger (1981). Although the main purpose of the tracking station is weather and sea-ice forecasting, the imagery can provide information to characterize many geophysical phenomena. In this article we describe a preliminary assessment of some applications of this imagery for sea-ice and ice plateau studies in the Antarctic. The satellite observations of the ice features described here were obtained during the austral summer 1981–82.

The HRPT system tracks National Oceanic and Atmospheric Administration (NOAA) satellites. The high-latitude location of McMurdo gives many overlapping passes per satellite. The advanced very-high-resolution radiometer (AVHRR) sensors aboard the satellites provide data in four spectral channels, with a subpoint resolution of 1 kilometer. The satellite data from all four channels are recorded on 7" high-density magnetic tapes (diameter 36 centimeters). In addition, hard-copy HRPT imagery, which covers an area of about 2,600 × 5,000 kilometers in one orbit at a scale of about 1:12,000,000, is produced from the infrared (IR) band (10.5–11.5 micrometers) and the visible band (0.58–0.68 micrometer). In addition, we have used LAC (local area coverage) data for the Ross Sea area having a scale of 1:7,000,000. Visual observations and photography were obtained through numerous flights conducted by the U.S. Navy.

We observed several features from the satellite data:

- *Movement of ice floes*. Ice floes form when sea ice breaks up; they generally follow the sea surface circulation. Movement of ice floes can be observed directly from the hard copies. Figure 1 shows the breakup of sea ice along the west coast of the Ross Sea on 3 December 1981. The giant ice floes outside Drygalski Ice Tongue are more than 30 kilometers in diameter. We watched them on satellite imagery for a month and a half. During that period they were rather stationary, drifting slowly to the southeast. From 3 December 1981 to 3 January 1982, the smallest floe close to the ice tongue moved 20 kilometers while the largest floe, away from the tongue, moved 60 kilometers. Some rotation of the floes also was observed. The smaller floes, farther seaward toward Cape Adare, moved in the opposite direction at speeds around 20 centimeters per second. The movement of these floes will be used to study sea surface circulation in a way similar to that described by Muench and Ahlnaes (1976).
- *Surface temperature of breaking sea ice*. To study the surface temperature distribution of water or ice with satellite imagery, it is necessary to enhance the imagery from taped data. When the general temperature range of the area under investigation is known, a table can be constructed to reflect that range (Ahlnaes 1981). Using that table, an IR image can be produced, enhancing the temperature structure. Figure 2 is an IR enhancement of figure 1. Here six distinct shades of gray were used to bring out the temperature to an accuracy of 1°C. We hope in the future to obtain actual surface temperature measurements to calibrate the satellite imagery.

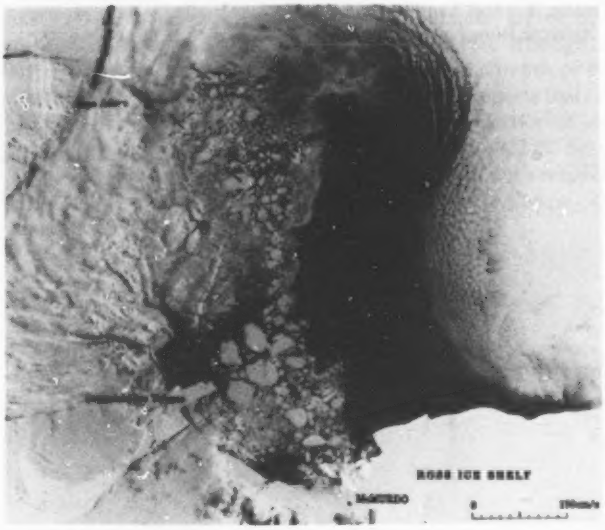

Figure 1. NOAA–6 VIS LAC (visible, local area coverage) satellite image of western Ross Sea, 3 December 1981, showing the breakup of sea ice. Vectors show drift of ice floes.

- *Icecap topography.* As we reviewed all HRPT satellite imagery for the entire antarctic continent, excluding the Peninsula, we observed a recurring pattern in the IR imagery for East Antarctica. The pattern consisted of semicircular features in shades of gray along the coasts of Wilkes Land and Queen Maud Land but most noticeable around the Amery Ice Shelf (see figure 3). Since figure 3 is an IR image, the tones of gray correspond to surface temperature and show an increase in temperature toward the coast. Since the plateau also slopes toward the coast, the question arises whether there is a relationship between surface temperature and topography. The superimposed ice-surface contours were taken from the General Bathymetric Chart of the Oceans (Canadian Hydrographic Service 1980). After our taped data are processed, we will look into this relationship. Benson (1962) noticed a linear relationship between altitude and mean annual temperature of 1°C per 100 meters on the Greenland ice sheet, where meteorological processes are similar to those in Antarctica. If we can find a relationship in our study, then satellite imagery can be used to monitor topographical changes corresponding to the mass balance of ice plateaus over periods of time.

We anticipate discovering many more applications when the taped data have been processed. Confirmation of these features, however, will require a comparison with ground truth and further analysis of satellite imagery specifically directed to the features that have been identified. Preliminary analysis suggests that AVHRR satellite imagery has great potential for antarctic ice studies.

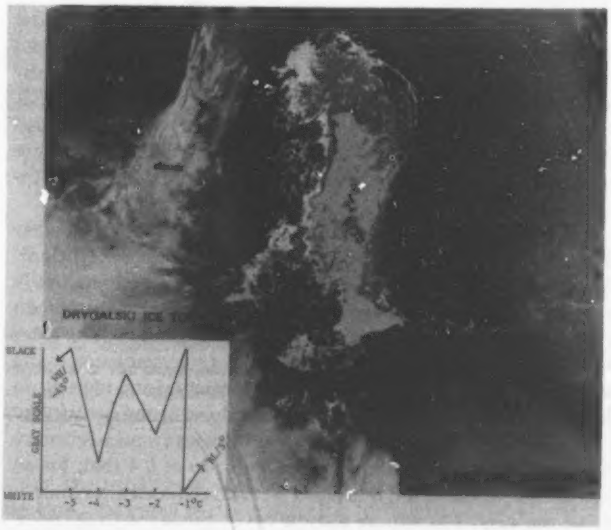

Figure 2. NOAA–6 enhanced IR LAC (infrared, local area coverage) satellite image of western Ross Sea, 3 December 1981, showing the surface temperature distribution of the breaking sea ice. Note the abrupt change from white to black, which corresponds to the ice edge. The "ice table" used is shown in the botton of the figure.

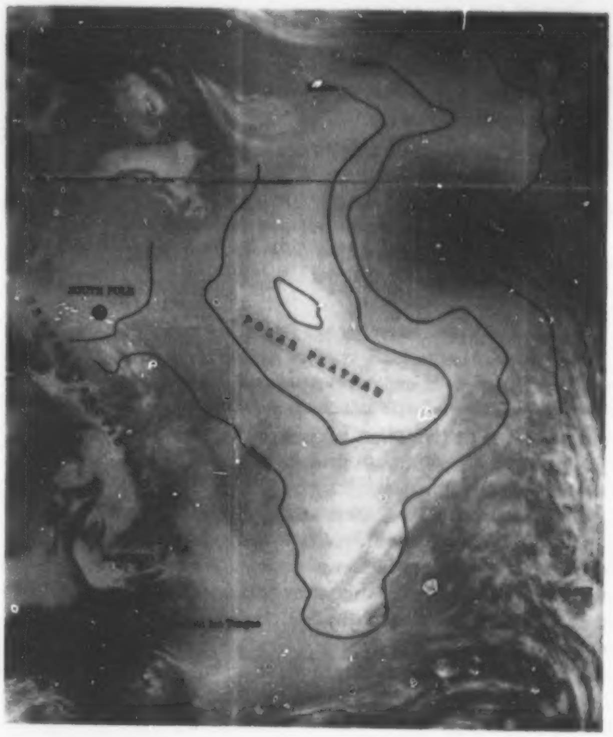

Figure 3. NOAA–7 IR HRPT (infrared, high-resolution picture transmission) satellite image, 23 December 1981, showing the surface temperature distribution of the east antarctic ice sheet with superimposed ice-surface elevation contours.

K. Ahlnaes was in the field 28 November 1981–28 January 1982. This work was supported by National Science Foundation grant DPP 80–24636.

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Sensitivity studies on a model of the Weddell ice pack

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A sequence of sensitivity studies has been run for a numerical model of the growth and decay of sea ice in the Weddell Sea and surrounding regions. The model formulations follow Parkinson and Washington (1979), and the model grid is a subset of the Parkinson and Washington grid (see figure 1). Each model run simulates 14 months, beginning on January 1. Outputs include (1) contour maps of ice thickness and concentration at the midpoint of each month, and (2) plots of the following variables as a function of time: ice thickness and ice concentration at grid points (5,7) and (9,4); ice thickness and concentration averaged over the grid squares within the Weddell Sea (figure 1) that contain some ice (labeled "ice-laden"); the area of ice-laden waters; and the area of actual ice coverage.

For many of the model inputs, a sufficiently large change in the input value causes a significant change in the model results. Of more relevance is whether a significant change in results can be produced by a "reasonable" change in the input. For the present studies, a change is considered "reasonable" if it falls within the variable's current range of uncertainty. For other studies, "reasonable" changes might be much greater than those used here (for instance, if the purpose of the study were to calculate the sea-ice response to a predicted increase in atmospheric carbon dioxide, or if it were to determine sea-ice extents under such changed boundary conditions as might have existed during a past major glaciation). The table lists the input variables examined in the current studies and the range used for each. For each set of model runs, only the variable in question was altered; the other variables were assigned "standard case" values.

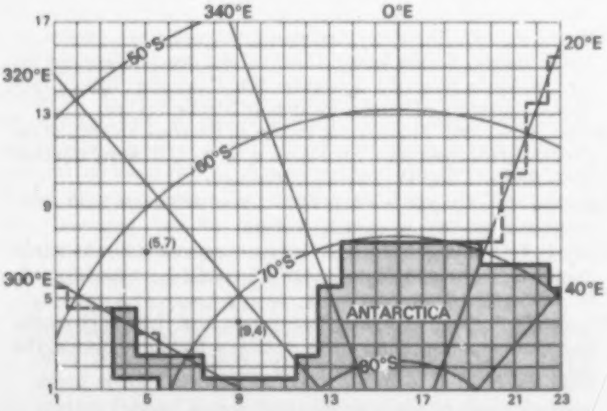

Figure 1. Grid structure of the model and geographical location. The dashed lines at 20°E and 300°E indicate the boundaries of the region defined for the analysis as the Weddell Sea.

Variables examined in model sensitivity studies and values used

Input variable	Value in standard case	Sensitivity-study range
Ice emissivity	0.97	0.95–1.00
Snow emissivity	0.99	0.95–1.00
Water emissivity	0.97	0.95–1.00
Solar radiation	formulation of Zillman (1972); varies spatially and temporally	0.90 × standard–1.10 × standard
Drag coefficient	0.0024	0.001–0.004
Ice albedo	0.50	0.40–0.60
Water albedo	0.10	0.05–0.15
Snow albedo	0.75	0.60–0.90
Turbulent exchange coefficients	0.00175	0.001–0.003
Snowfall rate	0.3 cm per month February–November	0–30 cm per month
Air temperatures	mean monthly climatological fields, from Taljaard et al. (1969)	standard ± 5 Kelvin
Winds	mean monthly climatological fields, from Taljaard et al. (1969)	a variety of alternate fields
Ocean heat flux	25 watts/sq meter	0–40 watts/sq meter

The sensitivity studies establish that the model is almost entirely insensitive to "reasonable" changes in long-wave emissivities of ice, water, and snow. The effect of increasing emissivities from 0.95 to 1.00 was imperceptible until month 12, when it increased the ice amount slightly. This increase suggests that increased absorption of long-wave radiation from the atmosphere, due to higher emissivities, is outweighed by increased emission from the surface to the atmosphere.

The model is somewhat more sensitive to changes in solar flux, short-wave albedos for ice and water, and drag coefficient. Increases in solar flux and/or decreases in ice albedo naturally result in a thinner ice cover, whereas decreases in water albedo have a stronger effect on lowering ice concentrations. The latter effect derives from increased absorption of solar radiation in the ocean and the consequent delay in ice formation and increase in lateral ice melt. The influence of ice albedo is strong early in the simulation, leading to central ice thicknesses in mid-February that are 30 centimeters lower for an albedo of 0.4 than for an albedo of 0.6. However, this effect is much reduced after March, when ice begins to acquire a snow cover. Since the drag coefficient (c_D enters the model calculations only through ice velocities, the effect of changing its value is to redistribute the ice; hence, its effect is not uniform over the grid.

The model is moderately sensitive to changes in snow albedo, turbulent heat exchange coefficients, and amount of snowfall. Model sensitivity to snow albedo is nonexistent in the first 2 months due to the absence of a snow cover, weak during the fall and winter when there is not much incident solar radiation, but strong during the subsequent melt season. In mid-September, ice extents are close to identical for snow albedos of 0.6 and 0.9, but by the middle of the following January total ice coverage in the 0.6-albedo case is only half the ice coverage in the 0.9 case.

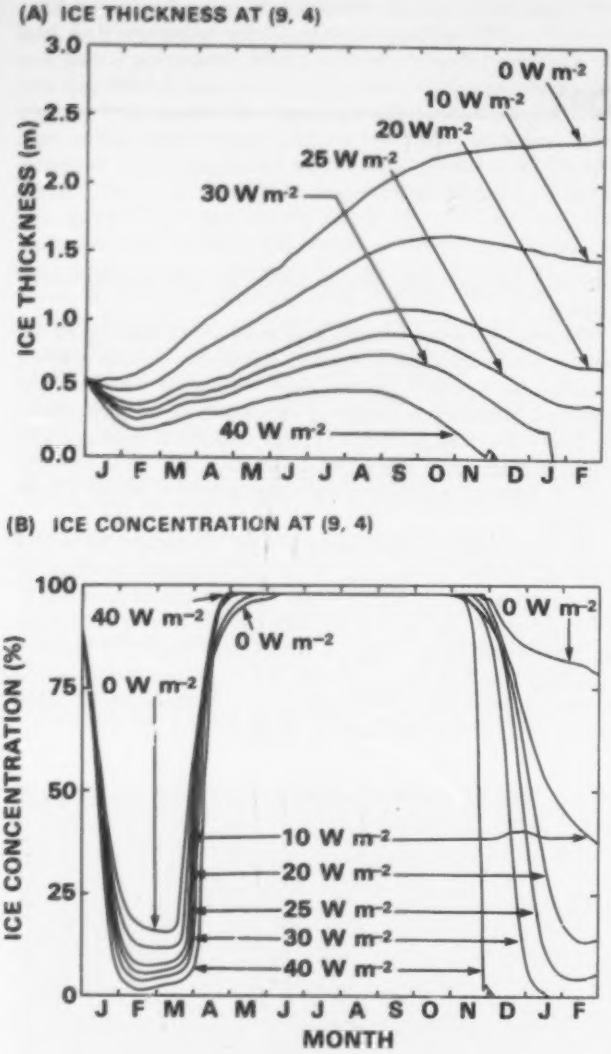

Figure 2. Sample results illustrating the sensitivity of the time sequences of ice thicknesses (A) and ice concentrations (B) at grid-square (9,4) to values of the ocean heat flux ranging from 0 to 40 watts per square meter.

Since the sensible and latent heats are calculated as positive upward, the effect of decreasing the turbulent exchange coefficients is to decrease the transfer of heat from the surface to the atmosphere and thereby to decrease ice thicknesses and concentrations. With turbulent heat coefficients of 0.001, ice thicknesses at grid point (5,7) are about half their values for turbulent coefficients of 0.003.

The additional insulation of the ice from the cold winter atmosphere provided by a thicker snow cover means that higher snowfall rates will decrease ice thicknesses. Numerically, the thicker snow cover increases the calculated snow-ice interface temperature, in turn reducing the temperature contrast between the bottom and top of the ice and thereby reducing the upward conductive flux through the ice. The decreased flux results in a lower growth rate of ice in winter and a higher decay rate in spring, as there is more energy available for melt at the ice/water interface.

The model proved highly sensitive to air temperatures, winds, and ocean heat flux (figure 2). Thus, it is especially important to insert proper values for these variables. The large effect produced by altering the wind fields is of particular concern since these fields can change radically over short time-spans. For two of the model runs, the mean climatological winds were replaced by 1974 winds from the Australian Bureau of Meteorology data sets. For one run, the winds were inserted as monthly averages and interpolated for each time step; for the other, they were inserted with 12-hour temporal resolution. The twice-daily winds produced a much stronger summer/winter contrast in the simulated ice cover, with almost no ice remaining in March but with at least a slight ice cover in almost every grid square by June. The effect of a variety of wind fields on the modeled Weddell polynya will be described elsewhere (Parkinson in preparation), as will the effect of atmospheric temperature increases on the entire southern ocean (Parkhurst and Bindschadler in preparation). The model's sensitivity to ocean heat flux has been detailed by Parkinson and Good (1982).

This work was supported by NASA's Oceanic Processes Branch in the Environmental Observations Division. I acknowledge with thanks the assistance of Michael R. Good of Computer Sciences Corporation.

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Weddell Polynya expedition

The U.S.-U.S.S.R. Weddell Polynya expedition

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From 9 October to 25 November 1981 a unique joint U.S.-U.S.S.R. oceanographic field effort, the U.S.-U.S.S.R. Weddell Polynya expedition (WEPOLEX-81), was carried out within the southern ocean sea ice (Gordon and Sarukhanyan 1982). The objectives of WEPOLEX-81 were to obtain the first comprehensive, interdisciplinary data set well before the end of winter seasonal sea ice cover and to study an active, open-ocean polynya.

The need for winter information in all of the oceanographic, sea ice, and atmospheric sciences within the southern ocean seasonal sea ice cover has long been recognized. However, the logistical difficulties of obtaining such a data set are formidable. To begin the task of fulfilling this important requirement, WEPOLEX plans were developed under the U.S.-U.S.S.R. Governmental Bilateral Agreement for Cooperation in World Ocean Studies.

The Soviet ship *Mikhail Somov* (length 133 meters, beam 18.8 meters), of the Arctic and Antarctic Research Institute of Leningrad, was used for the work. The expedition head was E. I. Sarukhanyan, the U.S.S.R. national coordinator for POLEX (Polar Experiment)-South. The U.S. component was led by the deputy chief scientist, A. L. Gordon. Each national group had 13 members, who were integrated into a single scientific team within each of the participating disciplines.

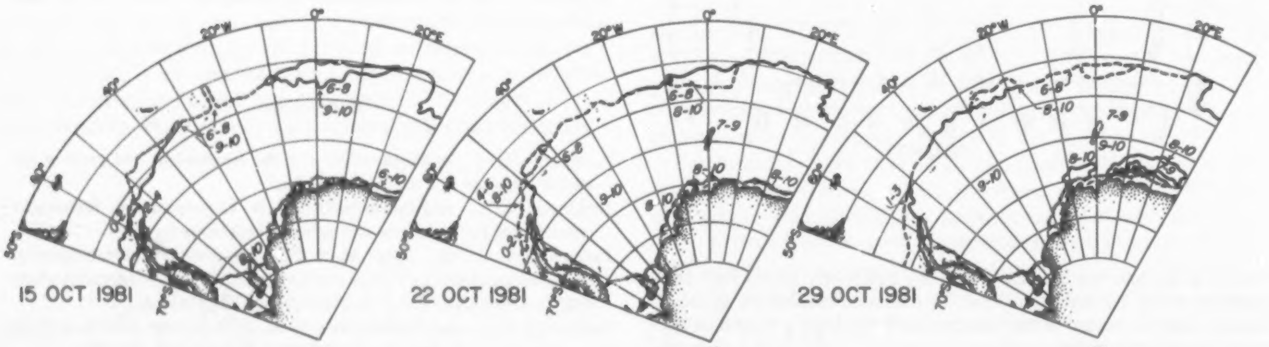

Figure 1. Extent and concentration of sea ice during the U.S.-U.S.S.R. Weddell Polynya expedition, October–November 1981, taken from U.S. Navy-National Oceanic and Atmospheric Adminstration Joint Ice Center maps.

After leaving Leningrad, the *Somov* stopped at Helsinki, Finland, on 9 September to pick up three members of the U.S. team and the U.S. equipment. With the aid of the Soviets, they undertook the difficult task of setting up the scientific apparatus and laboratory spaces for the expedition. The U.S. team provided most of the apparatus used during the cruise, including 7,000 meters of conducting cable for the conductivity-temperature-depth (CTD) work. During the transit from Helsinki, the cable was spooled onto the *Somov*'s winch, the CTD and computer equipment was installed and tested, and motor-generator sets were installed for converting 15 kilowatts of 50 hertz ship's power to 60 hertz power. During this time the ship's crew worked diligently to finish the routine maintenance tasks and modifications to the lab spaces that had not been completed in Leningrad because of *Somov*'s early departure.

The rest of the U.S. scientists boarded the *Somov* in Montevideo and headed for the ice on 9 October 1981. The ice edge near 5°E was reached at 56½°S on 20 October. The Greenwich meridian region was chosen for penetration into the ice because we believed we would encounter thinner ice with fewer pressure ridges there than further west and because the Weddell polynya, which formed in the 1974–76 period (Carsey 1980), occurred near 65°S and the Greenwich meridian.

Ice conditions during October and November 1981 were relatively heavy, with no well-developed, open-ocean polynya (figures 1 and 2). There were many leads—areas of reduced concentration—within the ice fields, which aided penetration into the ice interior. One of these leads, which was persistent, occurred near 65°S and the Greenwich meridian in approximately the same area that the Weddell polynya was observed in the mid-1970's. We were interested in this feature, but time requirements and the lack of a clear polynya signal made penetration farther south than our southernmost point of 62½°S counterproductive. The expedition track and station positions are shown in figure 3. The table (page 98) lists the Soviet and U.S. participants.

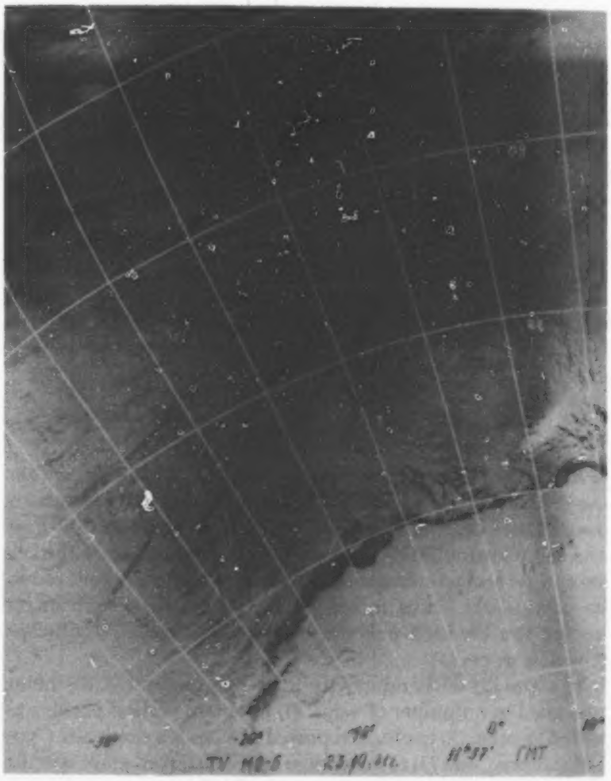

Figure 2. Satellite image transmitted from the Soviet Meteor satellite on 23 October 1981.

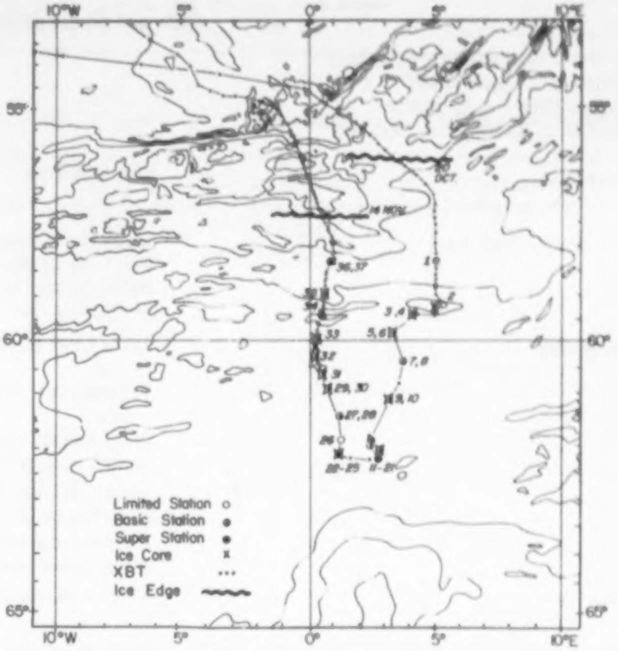

Figure 3. *Somov* track and observation sites during the U.S.-U.S.S.R. Weddell Polynya expedition. The limited stations included conductivity-temperature-depth (CTD) hydrographic stations. The basic stations included CTD and water column biology observation and atmospheric boundary layer observations. The super stations included all water column components. En route the thermal structure of the upper few hundred meters was observed with an expendable bathythermography system, surface chemistry was determined from water samples, and meteorological balloons were launched.

The articles that follow in this section describe the scientific components of WEPOLEX-81. Joint meetings of the U.S. and U.S.S.R. participants are planned for 1982 in the United States and for 1983 in the Soviet Union. A consolidated data report of scientific results will be prepared and distributed in 1983, and the scientific results will be published.

I wish to thank the participants of the U.S. and U.S.S.R. scientific teams and the *Somov* crew and officers, whose dedication led to the collection of an extensive array of high-quality data in a unique, previously unknown environment.

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U.S. and Soviet participants in WEPOLEX-81

Chief—E. I. Sarukhanyan
Deputy Chief—A. L. Gordon
Captain of *Somov*—F. A. Pesyakov

Discipline	U.S. personnel	U.S.S.R. personnel
Physical oceanography	Bruce Huber, Head, LDGO[a] David Woodroffe, LDGO Walter Richter, SIO[c] Jan Szelag, URI[d]	Ivan Chuguy, Head[b] Nikolai Antipov Nikolai Bagriantsev Vladimir Romanov
Chemistry	Arthur Chen (carbonate system), OSU[e] Joe Jennings (nutrients and silicon), OSU Gerry Metcalf (oxygen, carbonate system, and radon), WHOI[f]	Victor Haritonov Vladimir Feodorov
Biology	Jeanne Stepien (zooplankton), LDGO David Boardman (chlorophyll, primary productivity), LDGO Diane Clarke (diatoms), LDGO	Valyeri M. Zhuravlev (zooplankton)
Sea ice	Stephen Ackley, USACRREL[g]	Boris Sustenov Alexandre Samoshkin
Metaorology	Ed Andreas, USACRREL	Alexandre Makshtas Ed Lysakov
Velocity of sound in the ocean		Peter Bogarodski

[a] LDGO = Lamont-Doherty Geological Observatory.

[b] All Soviet personnel were from the Arctic and Antarctic Research Institute, Leningrad, except Valyeri M. Zhuravlev, who was from the NVIRO, Moscow.

[c] SIO = Scripps Institution of Oceanography.

[d] URI = University of Rhode Island.

[e] OSU = Oregon State University.

[f] WHOI = Woods Hole Oceanographic Institution.

[g] USACRREL = U.S. Army Cold Regions Research and Engineering Laboratory.

Physical oceanography during WEPOLEX–81

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The physical oceanographic objective of the U.S.-U.S.S.R. Weddell Polynya expedition (WEPOLEX-81) was to resolve the vertical and horizontal scales of the thermohaline stratification of the water column below the sea ice and, if possible, within the Weddell polynya. The low vertical stability of the southern ocean water column permits significant vertical fluxes of heat and salt (Gordon 1981). These fluxes strongly influence the sea ice budget and water mass conversion, and they are believed to be particularly active in the winter. Water mass conversion during the Weddell polynya period 1974–76 was significant (Gordon in press).

The Neil Brown conductivity-temperature-depth (CTD) meter was used in a number of ways: (1) to obtain vertical profiles to varied depths, (2) to obtain repeated profiles at a single site ("yo-yo" stations), and (3) to make time series observations at specific depths (see table; also see figure 3 in Gordon, *Antarctic Journal*, this issue). At the CTD time series sites, current meters (Soviet instruments) were used to obtain current shear information. A 12-bottle, 1.7-liter rosette sampler accompanying the CTD meter

Summary of conductivity-temperature-depth (CTD) stations by type and station number[a]

Water depth				Time series observations	
Shallow (≤ 1,000 m)	Intermediate (2,000–3,000 m)	Deep (>3,000 m)	Yo-Yo (No. of casts)	(duration)	(stratification feature)
1 (220 m)	2, 3, 5, 7, 13, 21, 22, 31, 36 (2,000 m)	17 (5,225 m)	4 (2)	12 (1.4 hr)	pycnocline
26 (1,000 m)		23 (5,425 m)	6 (8)	14 (4.6 hr)	T-max[b]
27 (1,000 m)		28 (5,200 m)	8 (6)	19 (13 hr)[c]	T-max
		29 (5,300 m)	10 (6)	25 (11.8 hr)[d]	T-max
	9, 11, 15, 33, 34, 35 (3,000 m)	30 (4,200 m)	12 (4)		
		32 (5,250 m)	14 (3)		
		37 (4,300 m)	16 (6)		
			18 (10)		
			19 (1)		
			20 (3)		
			24 (6)		
			25 (4)		

[a] Stations 1, 2, and 17–37 have CTD oxygen sensor data.

[b] T-max = Temperature maximum.

[c] 19—Soviet current meters deployed for 12 hours.

[d] 25—Soviet current meters deployed for 9 hours.

provided water samples for CTD calibration and for oxygen, nutrient, and biological study. The oxygen determinations were carried out by Gerry Metcalf. Observations by expendable bathythermograph (XBT) were made between CTD hydrographic stations (see figure 3 in Gordon, *Antarctic Journal,* this issue) to define better the horizontal scales within the thermal structure along the ship track. Surface water samples were obtained for determination of a variety of physical and biological parameters.

Several environmentally induced equipment problems deserve mention. The CTD meter was stowed on deck between stations and thus was exposed to temperatures well below the freezing point of seawater. To ensure good conductivity readings, the instrument had to be lowered to the temperature maximum layer to thaw out and then returned to the surface to begin each cast. The oxygen sensor failed at station 3, apparently because of freezing of the moisture in the Teflon membrane, resulting in its rupture. The sensor was not replaced until station 17, after which it performed well. Near-surface salinity samples did not agree well with CTD salinities, but deeper samples did, with a standard deviation of approximately 0.002. The large scatter in the surface samples may have been caused by ice crystal formation in the Niskin bottles during the short time the bottles were on deck before the samples were drawn. Finally, the cold air temperatures affected the underwater connectors used in the CTD wiring harness. We found that the rubber connectors had to be prewarmed before assembly on deck to ensure watertight mating.

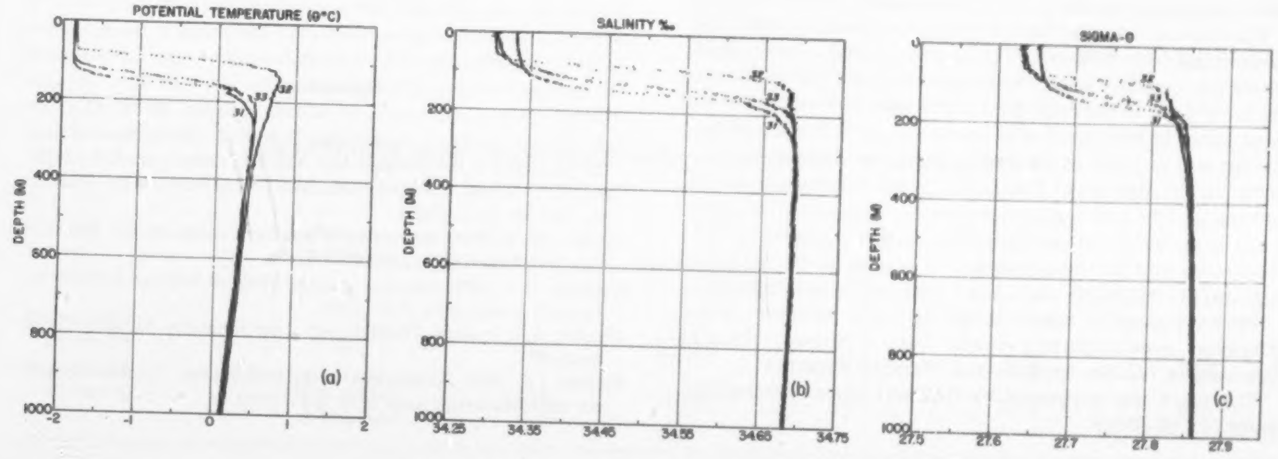

Figure 1. Potential temperature, salinity, and density (SIGMA-θ) at three neighboring conductivity-temperature-depth stations. Station 32 is within a pycnocline dome, while stations 31 and 33 are within the more "normal" stratification regime.

The *Somov* data provide the first modern information concerning the actual end-of-winter condition of the sea-ice-covered water column of the southern ocean. The data set is situated in what can be defined, according to data for the summer, as the Weddell Sea outflow of the cyclonic Weddell Gyre. This water is colder and fresher than the inflow found farther to the east and southeast. Although the *Somov* hydrographic data support this view, two interesting and new aspects of the stratification were found: the mixed layer is significantly deficient in oxygen, and the pycnocline has what can be called bumps, or domes, which are composed of relatively warm water more characteristic of the Weddell Gyre inflow.

The oxygen saturation level of the mixed layer (average thickness of 130 meters) was 85–88 percent. Since the ice shields the water from light and gas exchange (Chen, *Antarctic Journal*, this issue) and the water column biomass is quite low, the oxygen undersaturation may result from an admixture of oxygen-deficient Weddell deep water and surface water saturated with oxygen at the beginning of the ice-cover period. Using oxygen as a conservative parameter during the ice-cover period (about 5 months), it has been determined that the amount of deep water required to account for the undersaturation is 40 meters. Presumably this deep water enters the mixed layer by a combination of wind-induced Ekman upwelling, entrainment, and diffusion. This information provides the basis for estimation of the vertical flux of heat (30 watts per square meter during the 5 ice-cover months), salinity, and chemical parameters into the surface layer.

The pycnocline domes (figure 1) (page 99) are particularly curious features. The depth of the mixed layer over the domes is nearly half what it is elsewhere. The domes seem to have a lateral dimension of about 20 kilometers. Three occurrences were noted (stations 13, 27, and 32), though limited maneuverability of the ship in the ice precluded a full survey. As figure 1 shows, the deep water is significantly warmer below the pycnocline dome. The pycnocline domes may be entrained into the mixed layer more rapidly than is the case in a normal pycnocline situation. Mixed-layer temperatures at all stations were .02° to .05°C warmer than the calculated freezing point of seawater at the observed salinities (Doherty and Kester 1974). The temperature elevation over the freezing point at the pycnocline domes was .06° to .07°C. The relatively warm mixed-layer temperature above the domes may be evidence of the enhanced vertical flux.

The thermal structure and surface parameter traces along the return track from 61°S to 53°S (figure 2) reveal the varied stratification and surface water conditions across the transition from the ice interior to the open ocean. The transition region, or ice edge zone, is associated with increased vertical relief of isotherms and variation in the surface nutrients. As Stepien (*Antarctic Journal*, this issue) points out, water column biomass is increased in the ice edge zone relative to the interior of the pack ice. The ice edge zone is marked by smaller ice floes than are characteristic of the interior, as well as by noticeable swell propagation (Ackley, Smith, and Clarke, *Antarctic Journal*, this issue).

We are pleased to acknowledge the Soviet members of the physical oceanography team: Ivan Chuguy, Nikolai Bagriantsev, Nikolai Antipov, and Vladimir Romanov.

This work was supported by National Science Foundation grant DPP 80–05765.

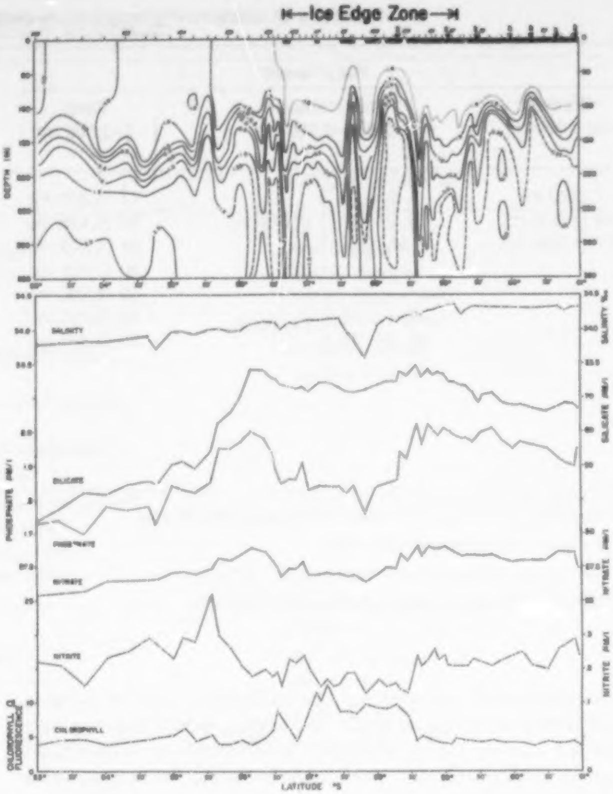

Figure 2. Thermal structure for the upper 350 meters approximately along the Greenwich meridian from 61° to 53°S. Expendable bathythermograph observations 81 to 146 are indicated as vertical tick marks, and the conductivity-temperature-depth thermal data are indicated by triangles. The thick horizontal bar along the sea surface denotes the sea ice cover. Meridional traces of various surface water parameters are given. Salinity was determined by AutoSal, nutrients by Auto Analyzer (see Jennings, Nelson, and Gordon, *Antarctic Journal*, this issue), and fluorescence by Turner Fluorometer (determination by D. Boardman). μ/l = micromoles per liter.

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Nutrient chemistry program during WEPOLEX–81

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The nutrient chemistry program of the U.S.-U.S.S.R. Weddell Polynya expedition (WEPOLEX-81) was designed to study the distribution and cycling of nutrients in the Weddell Sea under late winter/early spring conditions and to obtain the first data on particulate silica distributions and production/dissolution rates in the Weddell waters. An Auto Analyzer was used to determine nitrate, nitrite, phosphate, and silicate concentrations both in the water column and in samples from ice cores. In addition, samples collected and filtered at five hydrographic stations will be analyzed for biogenous and total particulate silicon in the laboratory at Oregon State University.

The vertical distribution of dissolved nutrients in the water column is similar to that of temperature and salinity: a very homogenous surface mixed layer some 60–110 meters thick overlying sharp gradients as concentrations increase to those of the Warm Deep Water. (See Carmack and Foster 1975 for water mass definitions.) Phosphate and nitrate concentrations decrease from a slight maximum in the Warm Deep Water at 400–800 meters (≥ 2.3 micromolar and ≤ 33 micromolar, respectively) to Weddell Sea bottom water values of approximately 2.2 micromolar and 31.5 micromolar, respectively. The silicate maximum (approximately 129 micromolar) is broad and lies below 1,000 meters, slightly deeper than the 0°C potential temperature isotherm. The silicate concentrations decrease gradually through the Weddell Sea Bottom Water until the −.5°C isotherm at approximately 3,000 meters, below which concentrations decrease more rapidly to near bottom minima of 117–120 micromolar.

Because ice conditions restricted the *Somov* to a relatively small sector within the Weddell Gyre, it is necessary to examine the data in context with data from other cruises in the same area to discern regional oceanographic features and temporal trends. Most of the recent historical nutrient data in the eastern Weddell Sea were collected during 1977 and 1978 *Islas Orcadas* cruises, and the overall oceanographic regime during the WEPOLEX cruise appears similar to that presented by Gordon (1980) on the basis of those cruises. Stations 3, 5, and 30–35 appear to be characteristic of the eastern extent or outflow of the Weddell Gyre, with the northernmost and southernmost stations exhibiting Gordon's "warm-saline" signal indicative of the influence of the circumpolar current. Surface nutrient concentrations are highest in the northernmost stations, decreasing somewhat in the Gyre proper. The increase in surface concentrations to the south of the central Weddell Gyre evident in the *Islas Orcadas* data was not observed, probably because ice conditions precluded *Somov's* reaching the vicinity of the Maud Rise.

A comparison was made of data from WEPOLEX and from the Geochemical Ocean Sections Study (GEOSECS), or using GEOSECS Atlantic station 89, which was at 60°S 0°E in January 1973. Disregarding the surface waters, in which seasonal changes should be most manifest, the agreement is very good. Silicate and phosphate values are in close agreement. Phosphate and nitrate values in the Warm Deep Water are higher at the GEOSECS station, but they become closer with increasing depth.

One preliminary finding concerning the distinct subsurface T_{min} (temperature minimum) layer, which Carmack and Foster (1975) call Winter Water, emerged from the comparison of WEPOLEX and GEOSECS data. Although Winter Water has long been thought to be a relic of the winter surface waters underlying the seasonal pack ice (Foster and Middleton 1979), the lack of actual winter data has precluded establishing this definitely. The table shows that, at the core of the Winter Water present at GEOSECS station 89, the nutrient concentrations as well as the temperature and salinity are almost identical to those found in the surface mixed layer (under the ice) at WEPOLEX station 35. Thus, our winter data set tends strongly to confirm that the local mixed layer in winter is the source of the appropriately named Winter Water.

The enthusiastic assistance of all of the Soviet scientists, ship's officers, and crew members—particularly the Soviet chemical technicians V. Fedorov and V. Hazitonov—contributed greatly to the success of the chemical programs.

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Winter water at GEOSECS station 89 and wintertime surface water at WEPOLEX station 35

Station	Pressure (decibels)	Potential temperature (°C)	Salinity (‰)	Silicate concentration (micromolar)	Phosphate concentration (micromolar)	Nitrate concentration (micromolar)
GEOSECS 89 22 Jan 73	75	− 1.830	34.383	75.7	2.03	29.4
WEPOLEX 35 21 Nov 82	entire surface mixed layer	− 1.858	34.358	75.7	2.04	29.3

Carbonate chemistry during WEPOLEX–81

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As part of the U.S.-U.S.S.R. Weddell Polynya expedition (WEPOLEX-81), my Soviet counterparts and I measured acidity and alkalinity of seawater samples on board the ship. Library seawater samples were collected for later measurements of total carbon dioxide (CO_2) and partial pressures of CO_2 (by T. Takahashi at Lamont-Doherty Geological Observatory) and for density and calcium (at Oregon State University). Some melted ice samples also were collected for measurements (at Oregon State University) of conductivity, chlorinity, density, calcium, and alkalinity. The objectives are (1) to use the calcium and carbonate data as water tracers, (2) to estimate the effect of pack ice on air-sea exchange of gases and on calcium and carbon cycles, (3) to quantify the CO_2 flux between atmosphere and the polar water, (4) to estimate the penetration depth of the fossil fuel CO_2, and (5) to quantify the error in densities calculated from the seawater equation of state.

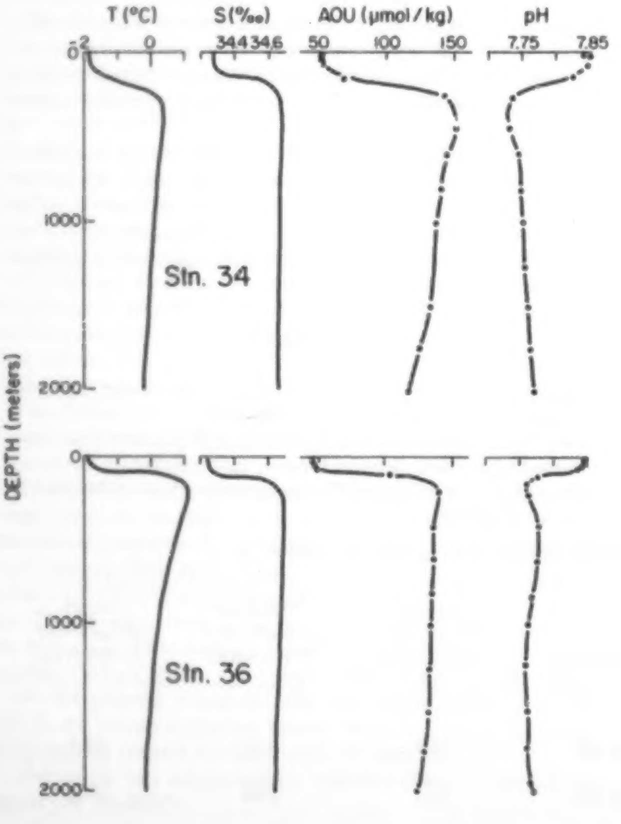

Figure 1. The vertical distributions of temperature (T), salinity (S), apparent oxygen utilization (AOU), and acidity (pH) at WEPOLEX stations 34 (59°30′S 0°30′E; 12 November 1981) and 36 (58°21′S 0°45′E; 13 November 1981). µmol/kg = micromoles per kilogram.

Preliminary analysis indicates that acidity is useful in identifying the source of waters. For instance, a large portion of the water near the broad S_{max} (salinity maximum) layer at station 34 (see figure 3 of Gordon, *Antarctic Journal*, this issue) seems to come from modified North Atlantic deep water (NADW). By the time NADW signal is incorporated into the Weddell Gyre from the circumpolar ocean, it is characterized by low acidity and high apparent oxygen utilization (see figure 1). In contrast, the warmer, saltier S_{max} layer at station 36, which represents circumpolar water just north of the Weddell Gyre, has a broad maximum acidity within the S_{max} layer from approximately 250 to 1,000 meters and lower apparent oxygen utilization than that observed in the S_{max} at station 34 (figure 1). This suggests that not as much decomposition of organic material has occurred in the circumpolar S_{max} water at station 36 as has occurred within the Weddell Gyre, represented by station 34.

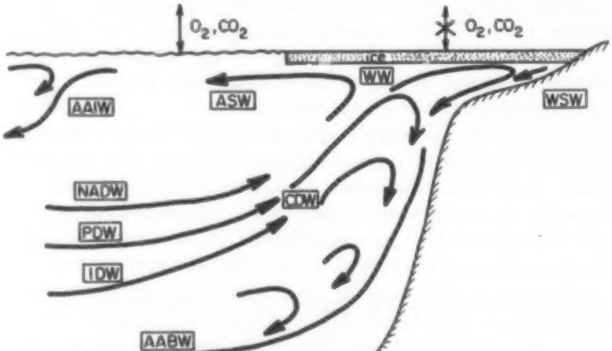

Figure 2. A schematic diagram showing the water masses in the southern ocean. The pack ice blocks the air-sea exchange of gases. AAIW = antarctic intermediate water; ASW = antarctic surface water; WW = winter surface water; WSW = western shelf water; NADW = North Atlantic deep water; CDW = circumpolar deep water; PDW = Pacific deep water; IDW = Indian deep water; AABW = antarctic bottom water.

Preliminary shipboard data indicate that the pack ice effectively blocks the air-sea exchange of oxygen and CO_2. Consequently, the homogeneous surface layer, which has approximately 30 percent deep water, is not in equilibrium with the atmosphere and contains less fossil fuel CO_2 than expected. Most of the winter surface water (identified as WW in figure 2) eventually is exposed to the atmosphere as the ice melts, and exchanges of gases with the atmosphere occur rapidly. Some of the surface water may flow southward beneath the ice toward the continental margin and thus undergo no air-sea gas exchange. There it mixes with western shelf water (WSW) and circumpolar deep water (CDW) to form antarctic bottom water (AABW) (Foster and Carmack 1976; Weiss, Ostlund, and Craig 1979). Since the circumpolar deep water was formed before the industrial revolution and the winter surface water is also deficient in the excess CO_2, the newly formed antarctic bottom water has little or no fossil fuel CO_2 (Chen 1982).

Laboratory analyses of library samples currently are being performed. Complete data interpretation and reports should be available by the summer of 1983.

I was assisted in the shipboard operations by V. Fedorov and V. Hazitonov of the Arctic and Antarctic Research Institute, U.S.S.R.; G. Metcalf and D. Woodroffe of the Lamont-Doherty Geological Observatory; the expedition chief, E. Sarukhanyan; U.S. chief scientist A. L. Gordon; and the *Somov's* captain and crew. This work was supported by Department of Energy grant 81 EV 10611 and by National Science Foundation grant OCE 80-18770.

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Carbon dioxide partial pressure in surface waters of the southern ocean

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Measurements of the partial pressure of carbon dioxide (CO_2) in surface waters were carried out during the U.S.-U.S.S.R. Weddell Polynya expedition (WEPOLEX-81) (Gordon, *Antarctic Journal*, this issue). The direction of the net transfer of CO_2 between the atmosphere and the oceans via gas exchange may be characterized in terms of the CO_2 partial pressures (pCO_2) in the surface ocean water and in the overlying atmosphere. If the pCO_2 in the atmosphere is greater than that in the surface water, the net CO_2 flux should be from air to sea, and thus the ocean acts as a CO_2 sink. If the partial pressures are equal, there should be no net transfer flux of CO_2 across the air-sea interface. Because seawater exerts a large temperature effect on pCO_2 (i.e., 4.3 percent per degree Centigrade when alkalinity and total CO_2 concentration in seawater are constant), the warm, low-latitude ocean waters are believed to have a greater pCO_2 than the atmosphere, and thus to act as a source of CO_2; the cold, high-latitude waters have a low pCO_2 and hence act as a CO_2 sink.

In the equatorial oceans, the observed pCO_2 values in surface water are much greater than anticipated for high temperatures (Broecker et al. 1979). This anomaly has been attributed to the upwelling of colder and CO_2-rich subsurface waters (Broecker et al. in press). In contrast, in the high-latitude northern oceans, including the Norwegian-Greenland Sea, the observed pCO_2 values are as low as one-half of the atmospheric value of about 340 microatmospheres, and these low values can be entirely accounted for by the low temperatures. The results of the Geochemical Ocean Sections Study (GEOSECS) expeditions during the austral summers of 1972, 1974, and 1978 (Broecker et al. 1979; Takahashi and Azevedo 1982) indicate that the surface water pCO_2 values in the southern ocean are not as low as those in the northern oceans but are nearly the same as those in the atmosphere, although the temperatures are as low as those in the northern oceans. Since the vertical mixing of ocean water is enhanced during the cold winter months, the CO_2 concentration in surface water in the southern ocean might be increased due to mixing with CO_2-rich subsurface waters, and hence the effect of cooling on the CO_2 partial pressure of seawater may be compensated by an increase in the total CO_2 concentration. Therefore, we hypothesized that the pCO_2 in the southern ocean surface water might not be reduced even during the period of a maximum cooling, and thus the ocean would not become a strong CO_2 sink.

The ship's track and the pCO_2 data obtained during the expedition are shown in figures 1 and 2. The pCO_2 contour lines in

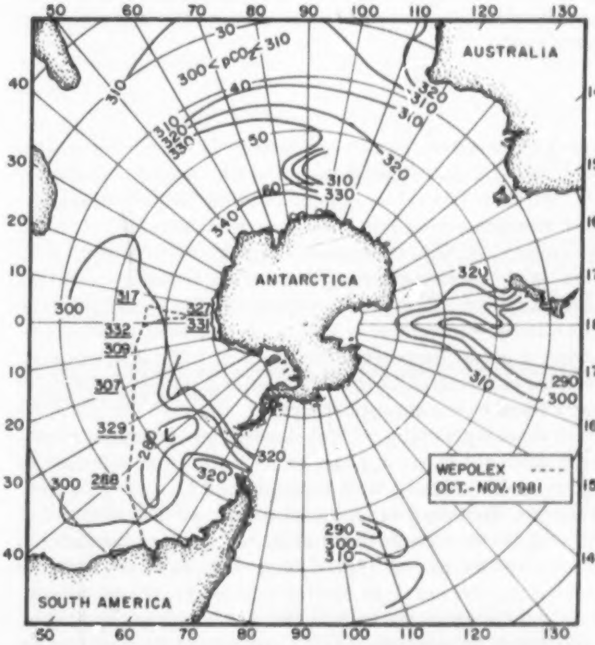

Figure 1. Distribution of partial pressure of CO_2 (pCO_2; expressed in 10^{-6} atmospheres) in surface waters of the southern ocean observed during the GEOSECS Atlantic expedition in January 1973, the GEOSECS Pacific expedition in February–March 1974, and the GEOSECS Indian Ocean expedition in February 1978. The ship's track and the pCO_2 data obtained during the WEPOLEX expedition in October–November 1981 also are indicated. The GEOSECS data are for the austral summer, and the WEPOLEX data are for the austral spring.

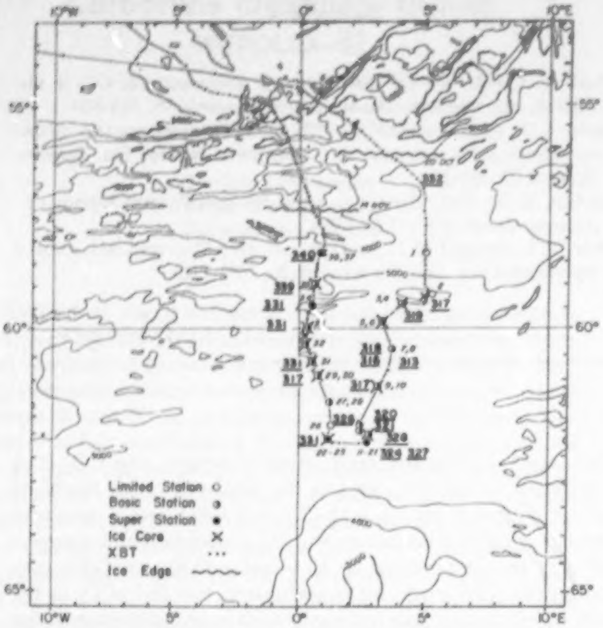

Figure 2. Ship's track and the partial pressure of CO_2 (pCO_2; expressed in 10^{-6} atmospheres) in surface waters observed during the WEPOLEX expedition in October–November 1981 on board the USSR *Somov*. The pCO_2 values are underlined; the station numbers are not. These measurements are the first observational data for surface water pCO_2 obtained in the ice-covered oceanic area during the austral spring.

figure 1 are based on the data obtained by Takahashi and associates during GEOSECS expeditions in the austral summers of 1973, 1974, and 1978. The values obtained during the present expedition (underlined in figures 1 and 2) in the austral spring of 1981 are similar to those of the previous expeditions and range from 307 to 340 microatmospheres. Atmospheric CO_2 measurements obtained during this expedition show that the partial pressure of CO_2 in the atmosphere is 341 (± 1.4) microatmospheres (assuming a mean barometric pressure of 1.000 atmosphere). Thus, the observed pCO_2 in surface water is slightly less than or nearly equal to the atmospheric pCO_2, although the temperature of water is generally −1.9°C. Accordingly, the surface water of the southern ocean appears to be nearly in equilibrium or slightly undersaturated with atmospheric CO_2 during the austral spring. Furthermore, the austral summer data of the GEOSECS expeditions indicate that the southern ocean waters are not far from equilibrium with atmospheric CO_2, as shown in figure 1, although there are some local variations. Therefore, we conclude that the southern ocean surface waters are nearly in equilibrium with the atmospheric CO_2 throughout the year and are neither a strong sink nor a source of CO_2. However, because of the absence of a large polynya area, which may be caused by a deep, vertical, convective chimney in ocean water, we did not have a chance to observe the significance of polynya in the CO_2 exchange between the atmosphere and oceans.

Our observations reveal a significant difference between the CO_2 chemistry of the southern ocean and that of the northern high-latitude oceans, including the Norwegian-Greenland Sea. The pCO_2 observed during the summers of 1979 and 1981 in surface waters of the Norwegian-Greenland Sea average about 230 microatmospheres at the mean temperature of 6.0°C; values as low as 160 microatmospheres at −0.1°C have been observed along the edges of ice fields. The mean pCO_2 value is about 70 percent of the atmospheric pCO_2 of 330 to 340 microatmospheres, indicating that the northern water is a strong sink for CO_2. These low pCO_2 values in surface water have not been observed in the southern ocean.

The warm North Atlantic surface water, which is nearly in equilibrium with the atmospheric CO_2, cools rapidly (in a time scale of weeks) as it flows northward into and through the Norwegian-Greenland basin and farther into the ice-covered Arctic Basin. Since the residence time of the surface water in the Norwegian-Greenland basin is expected to be short, while the time scale for CO_2 uptake by the surface water is of an order of a year or longer, the water does not have enough time to absorb significant amounts of CO_2 from the atmosphere. Furthermore, during the summer months, the vertical mixing between the surface and deep waters is expected to be at a minimum and the photosynthetic utilization of carbon in surface water is expected to be at a maximum. These factors contribute to lowering of pCO_2 in the surface water in the northern oceans.

In the antarctic circumpolar region, however, the water flows around the antarctic continent, driven by the westerly wind and unimpeded by major topographic barriers. The exchange rate of the surface water between the circumpolar water and the warm surface waters of the Atlantic, Pacific, and Indian Oceans generally is slow because they are separated by the Antarctic Convergence Zone. No coherent southward flow of the warm surface waters across the convergence zone into the circumpolar region exists. Thus, the residence time of circumpolar surface water is much longer than that in the Norwegian-Greenland Sea, and, accordingly, the southern ocean circumpolar surface water tends to be close to equilibrium with the atmospheric CO_2. Enhanced vertical mixing, which brings CO_2-rich deep water to the surface, and a minimum photosynthetic utilization of CO_2 during the austral winter tend to increase the pCO_2 on the surface water.

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Observations of pack ice properties in the Weddell Sea

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Among the programs undertaken during the U.S.-U.S.S.R. Weddell Polynya expedition (WEPOLEX-81) (Gordon, *Antarctic Journal*, this issue) was observation of ice as the ship was under way. These observations culminated in a daily map of ice conditions and a narrative observation log (Ackley and Smith 1982).

A section of the map prepared by the Soviet scientists who participated in the program is shown in figure 1. The ship's track as it left the ice is represented by the solid arrow line moving north and northwest. Locations of ice sampling stations taken along this line are given in Clarke and Ackley (*Antarctic Journal*, this issue).

The narrative log included information about ice concentration, ridging, amounts of thin ice and open water, and unusual ice features. As indicated in figure 1 and confirmed by the log, a transition in ice characteristics occurred between 60°20′ and 58°20′S latitude. In the southernmost regions the pack was characterized by fields of ice ("breccia") consisting mostly of medium-size floes (100–500 meters in diameter) and larger floes. Farther north, nearer the ice edge, the floes became smaller (20 meters or less in diameter) and surprisingly uniform. These northern observations coincided with observations of noticeable wave and swell penetration into the ice. Wave action apparently caused the breakup of the ice into smaller pieces. North of the area shown, ice of small floe size continued to be observed in lesser concentrations (6 tenths or less) for approximatey an additional 70 nautical miles.

The photographs in figure 2, taken at 0648 on 12 November and 0610 on 13 November, show the contrast in floe sizes between these two times. These characteristics also were observed on the inbound track at similar distances from the outer pack ice edge (first ice sighting).

On the basis of these observations, we divide the pack ice zone into three relatively distinct regions:

- *Ice edge region (within 0 to 60 nautical miles of the northern limit of pack ice).* This area is characterized by uniformly small floes (less than 30 meters in diameter), ice of less than 10 tenths concentration, and continuous wave propagation. Frontal structure in the ocean might also be associated with these ice properties, but these ice changes should be closely correlated with conductivity-temperative-depth (CTD) and expendable bathythermograph (XBT) observations to determine the extent of this relationship. Increases in biological activity (birds, mammals, zooplankton, and phytoplankton) also were apparent in this region. Ship navigation was unimpeded, and it was easy to maintain speeds in excess of 5 knots.
- *Ice edge–pack ice transition zone (within 60 to 160 nautical miles of the outer limit of pack ice).* The boundary between the ice edge region and the transition zone is not well defined. We traversed regions of continuous small floes (9 to 10 tenths concentration) coinciding with noticeable swell propagation. As the swell became severely attenuated and discontinuous in the southern regions, the floe sizes ranged from about 30 meters in diameter at the outer edge into a jumble of very large and some smaller floes. Similar features were apparent on the inbound track. We traversed nearly 100

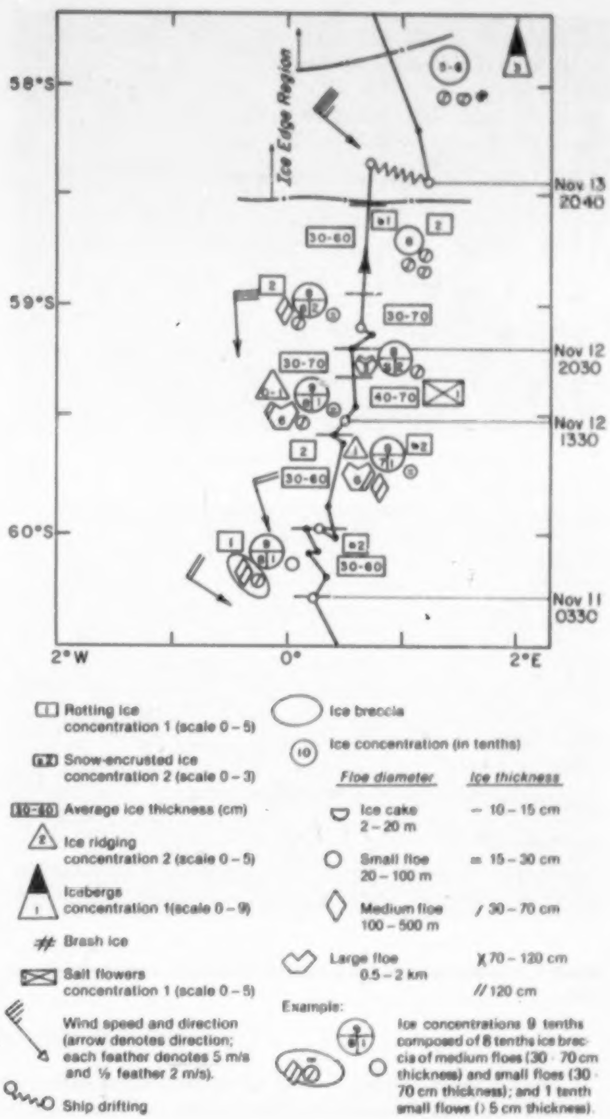
58°S
59°S
60°S
Ice Edge Region
Nov 13
2040
Nov 12
2030
Nov 12
1330
Nov 11
0330
30-60
30-70
40-70
2°W
0°
2°E
Rotting ice
concentration 1 (scale 0 – 5)
Snow-encrusted ice
concentration 2 (scale 0 – 3)
Average ice thickness (cm)
Ice ridging
concentration 2 (scale 0 – 5)
Icebergs
concentration 1(scale 0 – 9)
Brash ice
Salt flowers
concentration 1 (scale 0 – 5)
Wind speed and direction (arrow denotes direction; each feather denotes 5 m/s and ½ feather 2 m/s).
Ship drifting
Ice breccia
Ice concentration (in tenths)
Floe diameter
Ice thickness
Ice cake 2 – 20 m
— 10 – 15 cm
Small floe 20 – 100 m
= 15 – 30 cm
Medium floe 100 – 500 m
/ 30 – 70 cm
Large floe 0.5 – 2 km
X 70 – 120 cm
// 120 cm
Example:
Ice concentrations 9 tenths composed of 8 tenths ice breccia of medium floes (30 - 70 cm thickness) and small floes (30 - 70 cm thickness); and 1 tenth small flows (› 5 cm thickness).

Figure 1. Ship's track showing sea ice conditions. Symbols are explained in the table.

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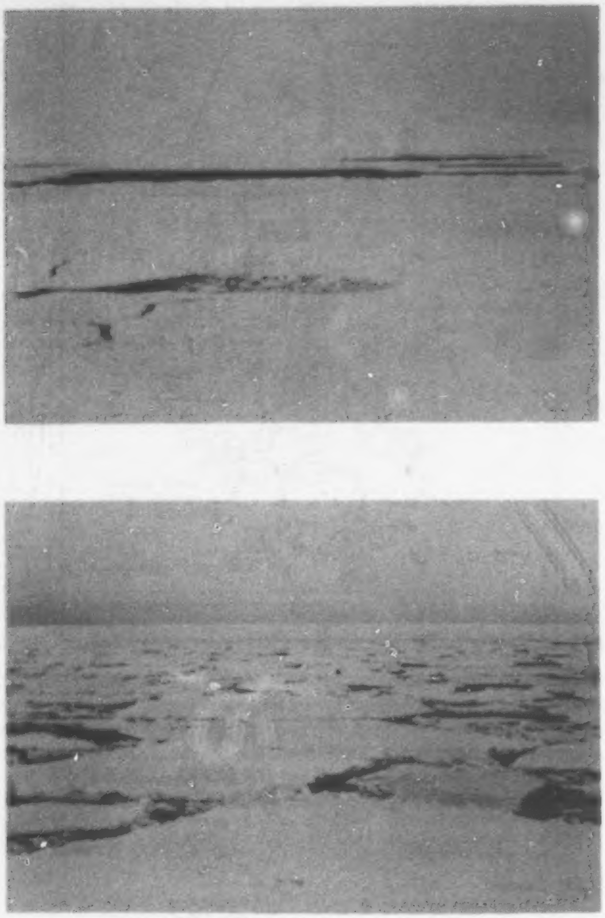

Figure 2. Photographs of sea ice conditions on 12 and 13 November 1981.

nautical miles of pack (160 to 60 nautical miles from the outer ice edge) from our first observations of swell motion in the ice until we encountered the "ice edge region." Ship navigation in this transition region was fairly easy, with only occasional difficulty encountered in crossing some of the larger floes. Figure 1 essentially brackets this region.

- *Deep pack (at distances greater than 160 nautical miles from the outer limit).* This region had ice concentrations usually in excess of 9 tenths (most commonly 10 tenths concentration). Narrow, parallel leads oriented according to the prevailing stress were the only open-water areas. Floes usually exceeded several kilometers in diameter. Ship navigation was exceedingly difficult, except where broad leads happened to coincide with the ship's course. These conditions were encountered between 150 and 180 nautical miles from the first (or last) ice sighting on both the inbound and outbound legs (south of the track shown in figure 1).

In most satellite microwave images, the ice edge-pack ice transition zone (60–160 nautical miles) appears as an area of lesser concentration. Our observations did not confirm this. We usually found ice concentrations of 9 to 10 tenths. We believe that this discrepancy arises from a change in the microwave signal; this change is caused by the infiltration of seawater into the snow/ice interface as a result of wave action breaking the floes and water surging into this porous layer. This process changes the surface emission characteristics of the ice at microwave frequencies. A comparison of the images received on board with our observations indicates that the Soviet meteorological satellites ("Meteor"), which use visible and infrared imagers, depicted the ice concentration in this region more accurately (that is, obtained higher values). Future work will include using our 300 photographs of ice conditions and the ice observation log (Ackley and Smith 1982) to correlate observed ice concentrations with those obtained from U.S. satellite mapping.

Also unexpected was our observation that noticeable swell propagation occurred at great distances from the outer pack limit. On both the inbound and outbound legs, we measured swell amplitudes of 0.25 meter or greater at distances greater than 120 nautical miles from the outer limit. This limit previously was thought to be about 60 nautical miles (100 kilometers) for the highly concentrated ice observed here (Wadhams 1980). A feature contributing to the deep pack propagation of swell in this region is the long wavelength (greater than 200 meters) and high amplitude (5–7 meters) of swell incident on the ice edge, characteristic of the long-fetch, high-wind regime of the southern ocean.

A complete report covering the entire cruise period and including interpretations of the ice map, the narrative log, sea level photographs, and satellite photographs is available from the authors.

We wish to thank Captain F. A. Pesyakov and the crew of the *Somov* for their support, and Edgar Andreas, Ivan Chuguy, and Ed Lysakov for their technical assistance. We also acknowledge the support of the other members of the Soviet science and meteorological support group, E. I. Sarukhanyan, chief scientist. This research was supported by National Science Foundation grants DPP 80-06922 (to the U.S. Army Cold Regions Research and Engineering Laboratory) and DPP 80-08011 (to the Lamont-Doherty Geological Observatory).

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Physical, chemical, and biological properties of winter sea ice in the Weddell Sea

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To investigate the physical, chemical, and biological regimes of drifting ice, an ice floe sampling program was carried out from the *Mikhail Somov* during the U.S.-U.S.S.R. Weddell Polynya expedition (WEPOLEX-81) (Gordon, *Antarctic Journal*, this issue). Sea ice algae is often an important constituent of the pack ice (Ackley, Buck, and Taguchi 1979; Buck and Garrison 1982; Buinitsky 1977; Garrison and Buck 1982; Hoshiai 1977; Sullivan and Palmisano 1982). At present, the ecology of the ice algae and its contribution to the overall productivity are poorly understood because the data set is limited. For example, the ice samples that we obtained comprise the first winter data set from antarctic drifting ice. We attempted to perform the most integrated data analysis possible because of the unique nature of these samples.

A total of 27 ice cores and 13 surface ice samples were taken at 11 sampling stations located between 59°21'S and 62°00'S (see Gordon, *Antarctic Journal*, this issue, for ice station locations). The ice cores were obtained using a Cold Regions Research and Engineering Laboratory ice auger as well as a Soviet coring device. The cores were analyzed for the following physical, chemical, and biological parameters: (1) ice structure, (2) salinity, (3) nutrients (silicate, phosphate, nitrite, and nitrate), (4) fluorescence, (5) chlorophyll *a*, (6) phaeo-pigment, (7) diatom species enumeration, and (8) bacteria. Figure 1 shows how the cores were subdivided to provide samples for each analysis.

Twenty of the cores have been analyzed so far—either on board ship or in the shore labs (see table). The cores measured between 29 and 159 centimeters, with an average length of 75 centimeters. The primary physical feature is the dominance (70 percent) of frazil ice structure as opposed to congelation ice. This substantiates previous work in the western Weddell Sea, which also indicated that frazil ice structure is more predominant in the Antarctic than in the Arctic (Ackley et al. 1980). The dominance of frazil ice structure indicates the importance of dynamic activity—winds, ice deformation, and ocean convection—in the formation of the ice cover.

The salinity range in the cores is 2.4 to 13.7‰, with the higher salinities usually within the upper 15 centimeters (figure 2) (page 109). Chemical analysis of the nutrients in the ice cores indicates that they do not follow a dilution curve. Standard seawater ratios—for example, between phosphate and nitrate and between nitrate and nitrite—are not conserved within the ice with regard to the nutrients. A comparison of the ice core surface samples with samples from the adjacent surface waters, which were obtained from conductivity-temperature-depth

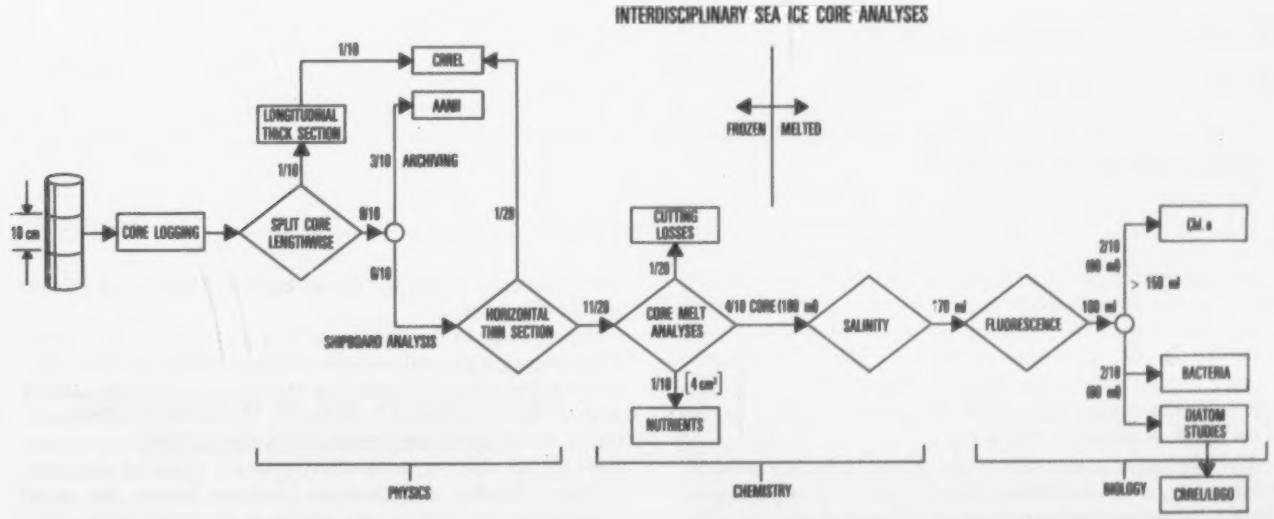
INTERDISCIPLINARY SEA ICE CORE ANALYSES
FROZEN
MELTED
10 cm
CORE LOGGING
SPLIT CORE LENGTHWISE
1/10
LONGITUDINAL THICK SECTION
1/10
CRREL
9/10
3/10
ARCHIVING
AANII
6/10
SHIPBOARD ANALYSIS
HORIZONTAL THIN SECTION
1/20
11/20
CORE MELT ANALYSES
1/20
CUTTING LOSSES
1/10
[4 cm²]
NUTRIENTS
4/10 CORE (180 ml)
SALINITY
170 ml
FLUORESCENCE
100 ml
2/10
(80 ml)
> 150 ml
Chl a
2/10
(80 ml)
BACTERIA
DIATOM STUDIES
CRREL/LDGO
PHYSICS
CHEMISTRY
BIOLOGY

Figure 1. From left to right, this figure indicates the successive core divisions and analyses performed on each 10-centimeter ice core sample. Fractions (e.g., one-tenth) or quantities (e.g., 170 ml) refer to portions of solid core or meltwater used in the various steps. AANII (Arctic and Antarctic Research Institute, Leningrad), CRREL (Cold Regions Research and Engineering Laboratory), and LDGO (Lamont-Doherty Geological Observatory) refer to the institutions where the designated samples are archived.

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Positions and averaged data for ice cores

Core number	Date	Position	Thickness (meters)	Average salinity (‰)	Average chlorophyll *a* (mg/m³)[a]	Percentage of frazil ice
1-22/O	22 Oct 81	59°21.5′S 5°13.2′E	.60	5.0 ± 1.3	.58	100
2-22/O	22 Oct 81	59°21.5′S 5°13.2′E	1.17	6.5 ± 2.2	.72	100
3-24/O	24 Oct 81	59°53.7′S 3°24.9′E	.60	5.3 ± 2.4	1.19	
4-24/O	24 Oct 81	59°53.7′S 3°24.9′E	.57	4.5 ± 1.0		100
5-26/O	26 Oct 81	61°10.7′S 3°03.9′E	1.52		1.27	82
6-26/O	26 Oct 81	61°10.7′S 3°03.9′E	.62	4.7 ± 1.3	.66	85
7-29/O	29 Oct 81	62°00.2′S 2°25.9′E	.32	10.7 ± 3.3	1.42	50
8-29/O	29 Oct 81	62°00.2′S 2°25.9′E	.60	6.6 ± 3	.15	78
9-1/N	1 Nov 81	62°11.2′S 2°53.8′E	.81	6.2 ± 2.8	1.00	71
10-1/N	1 Nov 81	62°11.2′S 2°53.8′E	.67	4.7 ± 1.2	1.12	?
11-1/N	1 Nov 81	62°11.2′S 2°53.8′E	.64	4.2 ± 1.1	2.52	87
12-4/N	4 Nov 81	62°12.4′S 1°03.5′E	.69	4.9 ± 1.4	.35	55
13-4/N	4 Nov 81	62°12.4′S 1°03.5′E	.68	6.4 ± 2.4	.63	60
14-4/N	4 Nov 81	62°12.4′S 1°03.5′E	.68	4.1 ± 0.71	.20	41
16-8/N	8 Nov 81	60°57.7′S 0°43.5′E	.68	4.0 ± 0.9	.33	24
17-8/N	8 Nov 81	60°57.7′S 0°43.5′E	.68	4.9 ± 2.2	.16	34
20-10/N	10 Nov 81	60°39.7′S 0°37.1′E	.78	5.3 ± 0.76	1.90	81
22-10/N	10 Nov 81	60°17.0′S 0°15.3′E	.54	5.1 ± 1.7	.24	100
24-11/N	11 Nov 81	60°05.1′S 0°14.2′E	.69	4.9 ± 2	.28	57
26-13/N	13 Nov 81	59°08.1′S 0°45.6′E	.54	4.9 ± 1.3	.43	15

[a] mg/m³ = milligrams per cubic meter.

rosette samples (Gordon and Huber, *Antarctic Journal*, this volume), shows several interesting differences. Silicate, phosphate, and nitrate are found in higher concentrations in the adjacent surface water than in the ice cores. Nitrite levels, however, showed the opposite trend: they are two to five times higher in the surface layer (0–20 centimeters) of the ice cores than in the adjacent surface water.

Chlorophyll *a*, a measure of the viable biological material, followed a pattern similar to that of nitrite. Chlorophyll *a* occurred in higher concentrations (1.415 milligrams per cubic meter), both in the surface layer of the ice cores and throughout the core, than in the adjacent surface water (0.1 milligram per cubic meter). The values of phaeo-pigment (degradation products of chlorophyll) in the cores range from 0.04 to 4.02 milligrams per cubic meter but do not appear to follow any pattern within the cores.

Figure 2 shows that, as was previously found (Ackley et al. 1979), there is a general trend for meltwater fluorescence, which is correlated with total biological material, to scale with salinity within individual cores. Comparing the salinity and fluorescence values for all cores combined, however, these two parameters do not seem to scale when different cores are grouped.

Marra, Burckle, and Ducklow (*Antarctic Journal*, this issue) have shown that diatoms are present at all sample levels in the ice cores, but in varying concentration and condition. Most of the valves in the surface layers are whole, whereas those in the middle and lower portions of the cores are fragmented. This indicates that active growth is occurring in the surface layers.

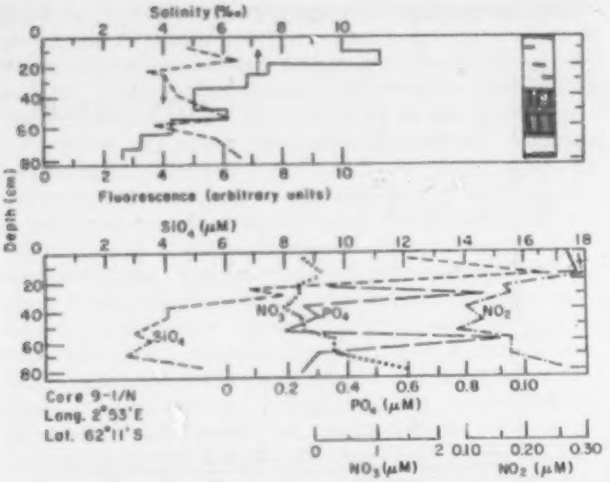

Figure 2. A typical core profile (core 9-1/N) showing salinity (solid line), fluorescence (dashed line), nutrients (in micromolars; SiO_4, silicate; NO_2, nitrite; NO_3, nitrate; PO_4, phosphate), and structure versus depth. In upper profile, arrows indicate which scale should be used. In the structural cartoon, circles indicate frazil ice structure and vertical lines show congelation or columnar ice structure.

Further confirmation of this comes from K. R. Buck (personal communication), who has identified isogametes from two pennate species in cores 22-10/N, 24-11/N, and 26-13/N. The presence of these isogametes, which are formed as part of the sexual cycle, substantiates our belief that the diatoms are reproducing in the surface layers of ice cores.

With the remaining seven cores we will be able to sample for each parameter at 10-centimeter intervals, rather than integrate several levels as we did for chlorophyll *a* and diatom species in the shipboard analysis. In addition to this refinement in sampling technique, we anticipate using a multivariate analysis of all the parameters rather than a simple comparison of two parameters.

We wish to thank Captain F. A. Pesyakov and the crew of the *Mikhail Somov* for their support, as well as our colleagues Edgar Andreas, David Boardman, Kurt Buck, Joe Jennings, David Woodroffe, and Alexander Samoshkin for their technical assistance. We also acknowledge the support of the other members of the Soviet science and meteorological support group, E. I. Sarukhanyan, chief scientist. This research was supported by National Science Foundation grants DPP 80-06922 (to the U.S. Army Cold Regions Research and Engineering Laboratory) and DPP 80-08011 (to Lamont-Doherty Geological Observatory).

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Zooplankton in the Weddell Sea, October–November 1981

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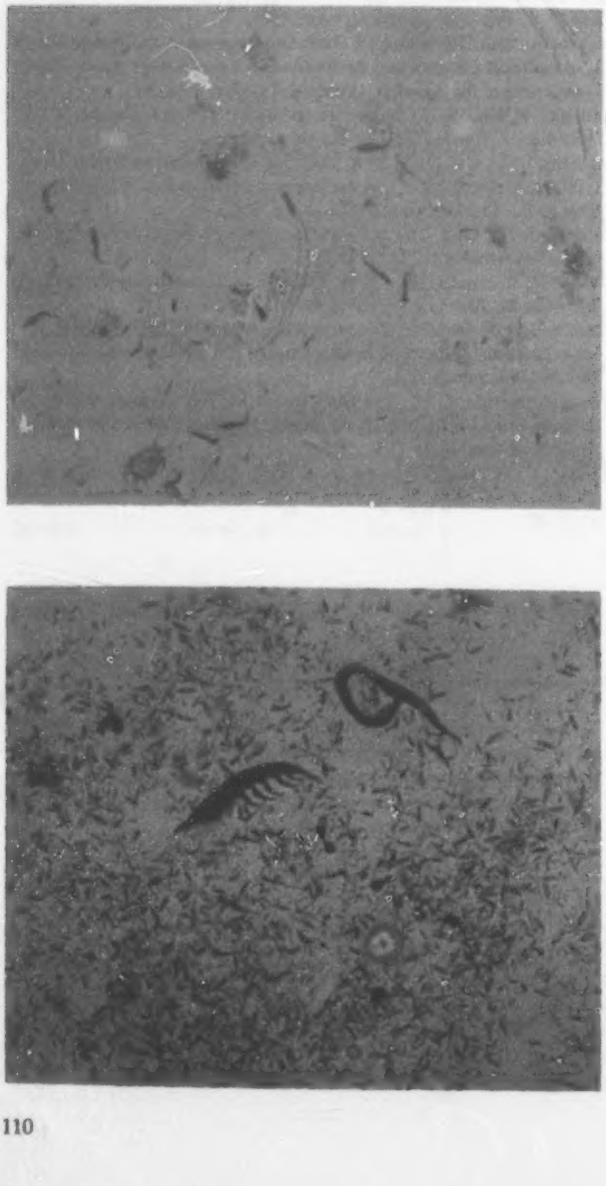
Zooplankton was collected beneath the pack ice of the Weddell Sea and at the ice edge during the Weddell Polynya expedition (WEPOLEX-81) (Gordon, *Antarctic Journal*, this issue). The Soviet research vessel *Mikhail Somov* entered the ice in mid-October near 56.5°S 5°E and penetrated as far south as 62.5° before leaving the ice in mid-November at approximately 58°S. To characterize the Weddell Sea zooplankton community, with special emphasis on the distribution, abundance, biomass, feeding habits, and reproductive state of krill, macrozooplankton was collected beneath the ice and at the ice edge.

Paired 500-micrometer and 1,000-micrometer mesh, 0.75-meter nets were fished routinely from 0–200 meters and 0–500 meters and occasioally from 0–1000 meters. Ice conditions limited the sampling to vertical hauls. Krill also were collected for feeding studies using the gut fluorescence method (Mackas and Bohrer 1976) and microscopic examination aboard ship.

The results show several striking differences between the pack ice and ice edge (see figure 2 of Gordon and Huber, *Antarctic Journal*, this issue) in October–November in terms of species of krill and total zooplankton abundance and biomass. *Euphausia superba*, the dominant species of antarctic krill, was observed at the ice edge in both mid-October and mid-November, although not in swarm concentrations. With the exception of a few isolated juveniles, however, this species was not collected or observed within the pack ice, where *Thysanoessa macrura* was the dominant species at all stations. There was a dramatic difference in total zooplankton biomass and abundance between the pack ice and ice edge (Figure 1). Biomass in the upper 200 meters and 500 meters increased from means of 1.2 and 1.0 milligrams per cubic meter beneath the ice to 2.9 and 4.5 milligrams per cubic meter at the ice edge; total abundance in the upper 200 meters and 500 meters increased from 3 and 5 per cubic meter beneath the ice to 25 and 42 per cubic meter at the ice edge. Biomass and abundance figures at the ice edge actually

Figure 1. Silhouette photographs (Ortner et al. 1979) of typical zooplankton samples taken within the pack ice (top panel) and at the ice edge (bottom panel). Both samples were collected with a 500-micrometer mesh net hauled vertically from 0 to 200 meters. Photographs show one half of the original sample.



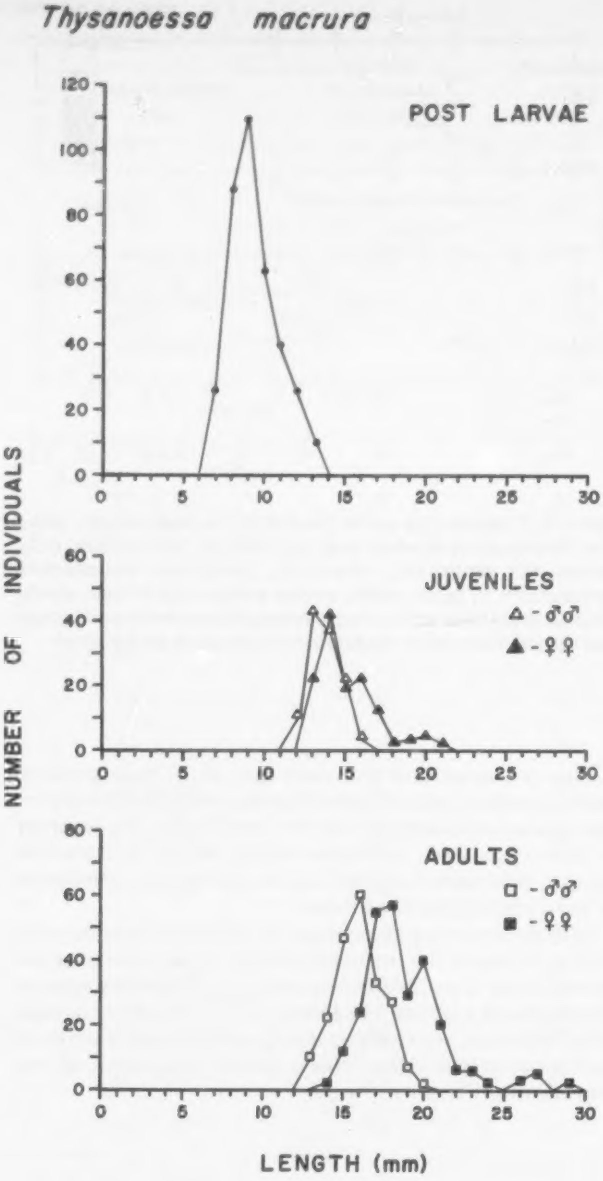


Figure 2. Total length of *T. macrura* post-larvae, juveniles, and adults collected within the pack ice.

should be higher, because the vertical tows did not adequately sample the *E. superba* population observed. The increases in zooplankton abundance and biomass at the ice edge parallel the increase in chlorophyll *a* and photosynthesis reported by Marra, Burckle, and Ducklow (*Antarctic Journal*, this issue).

T. macrura was present throughout the pack ice, reaching a maximum abundance of 9 per cubic meter in the upper 200 meters and accounting on average for 32 percent and 27 percent of total biomass in the upper 200 meters and 500 meters, respectively. Since all of the hydrographic stations during WEPOLEX were within the ice (figure 3 of Gordon, *Antarctic Journal*, this issue), it was possible to collect many specimens of *T. macrura*. Total length and stage of sexual maturity were determined for more than 1,000 individuals (figure 2). The *T. macrura* population sampled consisted of three groups: post-larvae (secondary sexual characteristics not visible), juveniles (immature males and females and females with spermatophores), and adults (mature males and females with ripening gonads). The developmental stage of the ovaries of the ripening adult females suggests that spawning had not begun. Females spawn at stage IV, yet all females examined were in stage II or III (Roger 1974). It is known that under the proper conditions the ovaries can mature to stage IV within a week (Zhuravlev, personal communication). Chlorophyll levels beneath the ice were low (0.1 microgram per liter) (see Marra, Burckle, and Ducklow, *Antarctic Journal*, this issue), and gut fluorescence measurements and visual examination of stomach contents indicated that *T. macrura* were not feeding. Perhaps the springtime retreat of the ice, which brings increased productivity in the formerly ice-covered water column, triggers the maturation of the ovaries to stage IV, thus initiating spawning by *T. macrura* in the Weddell Sea. Such a spawning response is possible since *T. macrura* is known to spawn in the Scotia Sea in spring (Makarov 1979).

D. Boardman, D. Clarke, and V. Zhuravlev assisted in the collection of samples. V. Zhuravlev measured *T. macrura* and determined stages of maturity, and C. Newcomer provided technical assistance. This research was supported by National Science Foundation grant DPP 80-08011.

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Sea ice and water column plankton distributions in the Weddell Sea in late winter

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During the joint U.S.-U.S.S.R. Weddell Polynya expedition (WEPOLEX-81) (see Gordon, *Antarctic Journal*, we measured chlorophyll *a*, phytoplankton photosynthesis parameters, diatom distributions, and bacterial densities, in both the sea ice and the water column. Our investigations were part of a larger effort to obtain a comprehensive set of oceanographic data for wintertime conditions in the Weddell Sea. The measurements were carried out aboard the Soviet ship *Mikhail Somov*. *Somov* entered the pack ice at approximately 57°S 4°E on 20 October 1981 and proceeded south about 300 nautical miles (550 kilometers) into the pack ice before returning to the ice edge 24 days later.

Water column distributions. We collected water samples by bucket and, at discrete levels throughout the upper water column, using Niskin samplers attached to the conductivity-temperature-depth (CTD) rosette. Chlorophyll *a* concentrations (analyzed fluorometrically) were very low beneath the pack ice and increased by a factor of 2 at the ice edge (figure 1). According to the thermohaline distribution, the water column may have been more stable at the ice edge than beneath the pack ice. Diatom populations at the ice edge station were dominated by *Corethron hystrix* and *Chaetoceros sp.* Beneath the pack ice, a variety of species was found, including *Nitzschia closterium*, *N. curta*, and *Tropidoneis vanheurckii*.

The pack ice and ice edge populations differed most strikingly in their photosynthetic characteristics. Surface samples collected from each locale were incubated aboard ship in fluorescent light incubators under a range of light intensities (3–1,000 microEinsteins per square meter per second) and at near-ambient temperatures. Photosynthetic carbon fixation (as carbon-14 uptake) was plotted against the light intensity of incubation. For stations in the pack ice, maximal photosynthesis (normalized to chlorophyll *a*), or P^B_{max}, averaged 1.5 (standard error, ± 1) and the initial slope of the photosynthesis-light intensity relationship (α) averaged 0.014 (standard error, ± 0.010). No significant photoinhibition was observed. At the ice edge, P^{B}_{max} and α increased fourfold. Since the only environmental parameter that changed significantly between the pack ice stations and the ice edge was ice cover, the higher P^{B}_{max} and α values at the ice edge may represent an adaptation to higher light intensities in the water column resulting from lower cellular chlorophyll *a* contents.

Sea ice communities. The late winter pack ice contained an active community of microorganisms. Ice cores, obtained with the Cold Regions Research and Engineering Laboratory ice augur (Clarke and Ackley, *Antarctic Journal*, this issue) and sectioned and analyzed aboard ship, showed chlorophyll *a* concentrations that were an order of magnitude greater than those beneath the ice, typically ranging from 0.5 to 3 micrograms per liter. The diatom community was similar to that in the water column. In the top portion of the ice column, the flora was dominated by *N. closterium* or *T. vanheurckii*. There were relatively few diatom cell fragments. The middle and lower portions of the ice column had a more diverse assemblage (e.g., *N. closterium*, *N. curta*, *N. turgiduloides*, and *T. vanheurckii*), and the ratio of whole cells to cell fragments was low, about 1.

Bacteria in the ice were enriched relative to the water below. Within the ice, and at the depth of the chlorophyll maximum, bacterial density was approximately 10^{9} cells per liter, while in the water below density was approximately 10^{8} cells per liter. However, the cell counts mask large differences in cell sizes between the populations (figure 2). Using a carbon conversion factor based on cell volume, the bacteria in the ice would represent about 700 milligrams of carbon per cubic meter, while the bacteria in the water column would represent only 0.7 milligram per cubic meter.

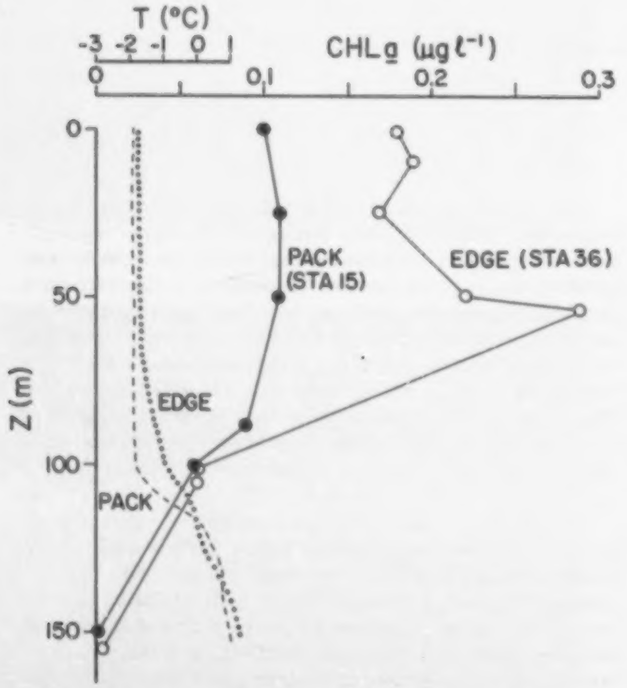

Figure 1. Vertical distribution of chlorophyll *a* (CHL *a*), in micrograms per liter, and temperature (T) for a station in the ice edge zone (station 36) and a station within the pack ice (station 15). Z = depth in meters.

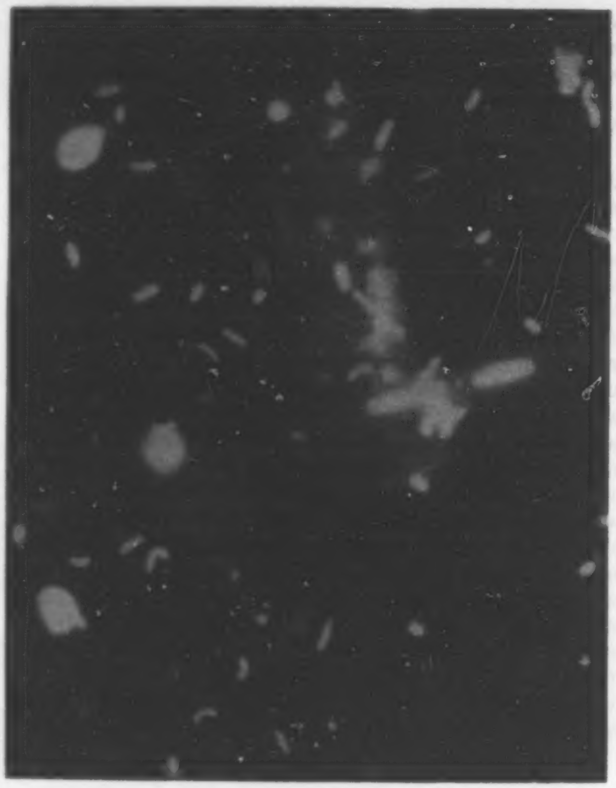

Figure 2. Epifluorescent photomicrographs of the heterotrophic community components in the ice column. The bacteria are about 1.0 micrometer long. Note also the unidentified flagellates, which number approximately 10^{7} per liter, and the *Fragilaria sp.* and the *N. closterium* cells.

While most of the diatoms may be incorporated into the ice during ice formation, the further growth of *N. closterium* and *T. vanheurckii* is indicated by their numerical dominance and by their occurrence in regions where the ratio of whole cells to fragments is high. Also, the large, abundant, and morphologically distinct bacteria found within the ice implies an active, heterotrophic community. If true, this is to our knowledge the first example of both active algal and bacterial growth within the pack ice of the Weddell Sea.

D. Boardman and D. Clarke performed the at-sea collections. We thank S. F. Ackley for providing the ice core samples and for comments on the manuscript. This research was supported by National Science Foundation grant DPP 80-08011.

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Atmospheric boundary layer measurements in the Weddell Sea

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The atmospheric boundary layer component of the Weddell Polynya expedition (WEPOLEX-81) was one of the most intensive measurement programs ever carried out over floating ice in the Antarctic. Our research involved four distinct, yet complementary, sampling programs: upper-air soundings, surface-layer profiling, spectral measurements of surface-layer turbulence, and routine meteorological observations.

Two radiosonde systems for upper-air sampling were available on the *Mikhail Somov*. We used the MicroCORA automatic sounding system, manufactured by Vaisala of Helsinki, Finland, to make soundings of wind velocity, temperature, humidity, and pressure at 0000 and 1200 Greenwich mean time each day. Between 15 October and 16 November 1981 we collected 65 sets of such profiles, usually from the surface to an altitude of 20 kilometers. With an Airsonde system made by A.I.R., Inc., of Boulder, Colorado, we made closely spaced soundings of temperature, humidity, and pressure to roughly 5 kilometers in regions of special interest. We made 46 Airsonde soundings, including transects as the *Somov* entered the ice on 20 October and recrossed the marginal ice zone during the period 11–14 November. During both of these transects, the wind blew from the open ocean onto the ice, so modification of the planetary boundary layer was dramatic. On two occasions we attached both the MicroCORA and the A.I.R. radiosondes to the same helium-filled balloon and made simultaneous soundings to compare pressure, temperature, and humidity data obtained from the two systems (Andreas and Ackley in preparation).

The standard meteorological observations made on the *Somov* included recordings every 3 hours of wind speed and direction, air, water, and dew-point temperatures, ice conditions, and cloud cover. In addition, total Sun and sky radiation, reflected shortwave radiation, net all-wave radiation, and surface (ice) temperature were recorded every hour. With this data set we will estimate the surface energy budget at hourly intervals along the *Somov*'s track through the ice.

We collected 21 sets of surface-layer profiles of wind speed, temperature, and dew point with a boom deployed from the helicopter deck of the *Somov* (figure 1). Because the biological

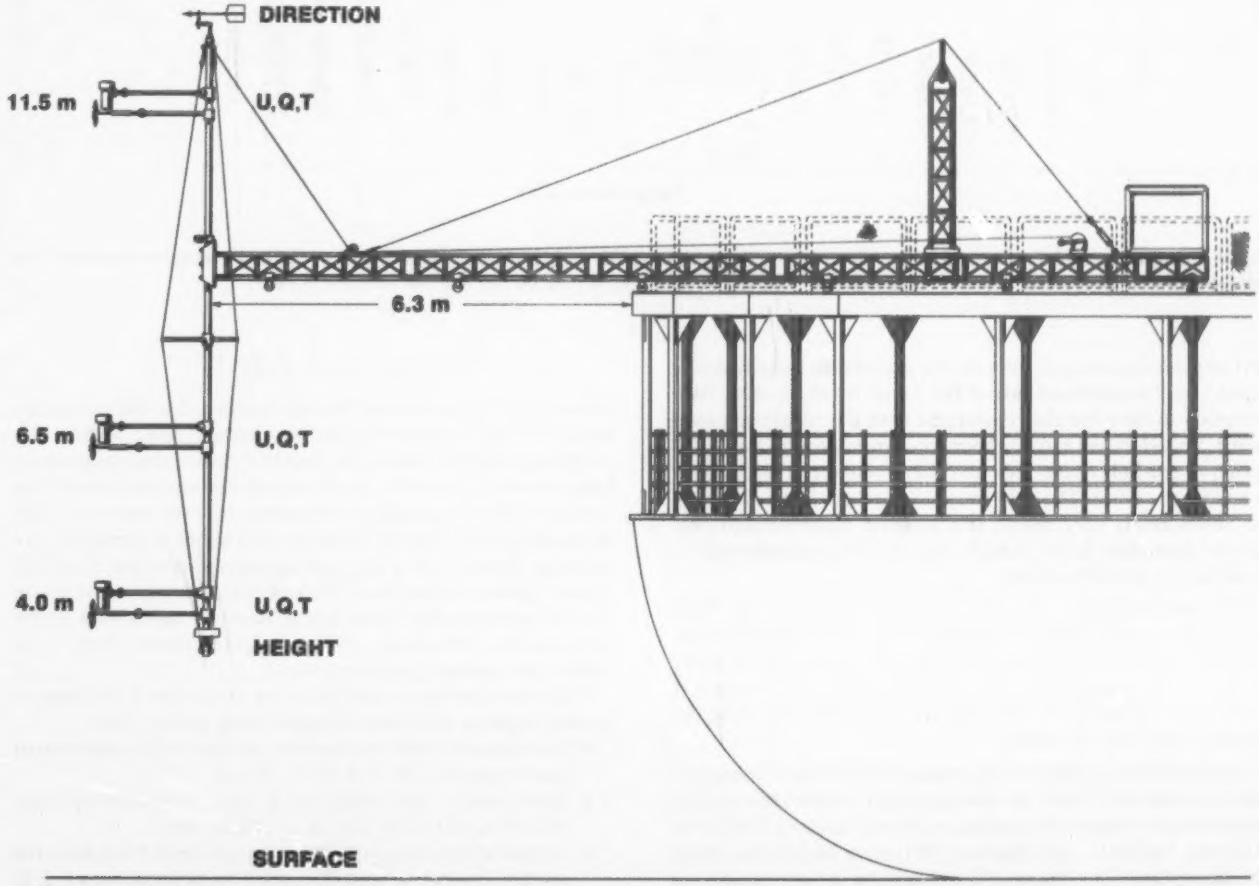

Figure 1. The profiling mast deployed from the helicopter deck. U, Q, and T indicate, respectively, the location of instruments for measuring wind speed, dew point, and temperature.

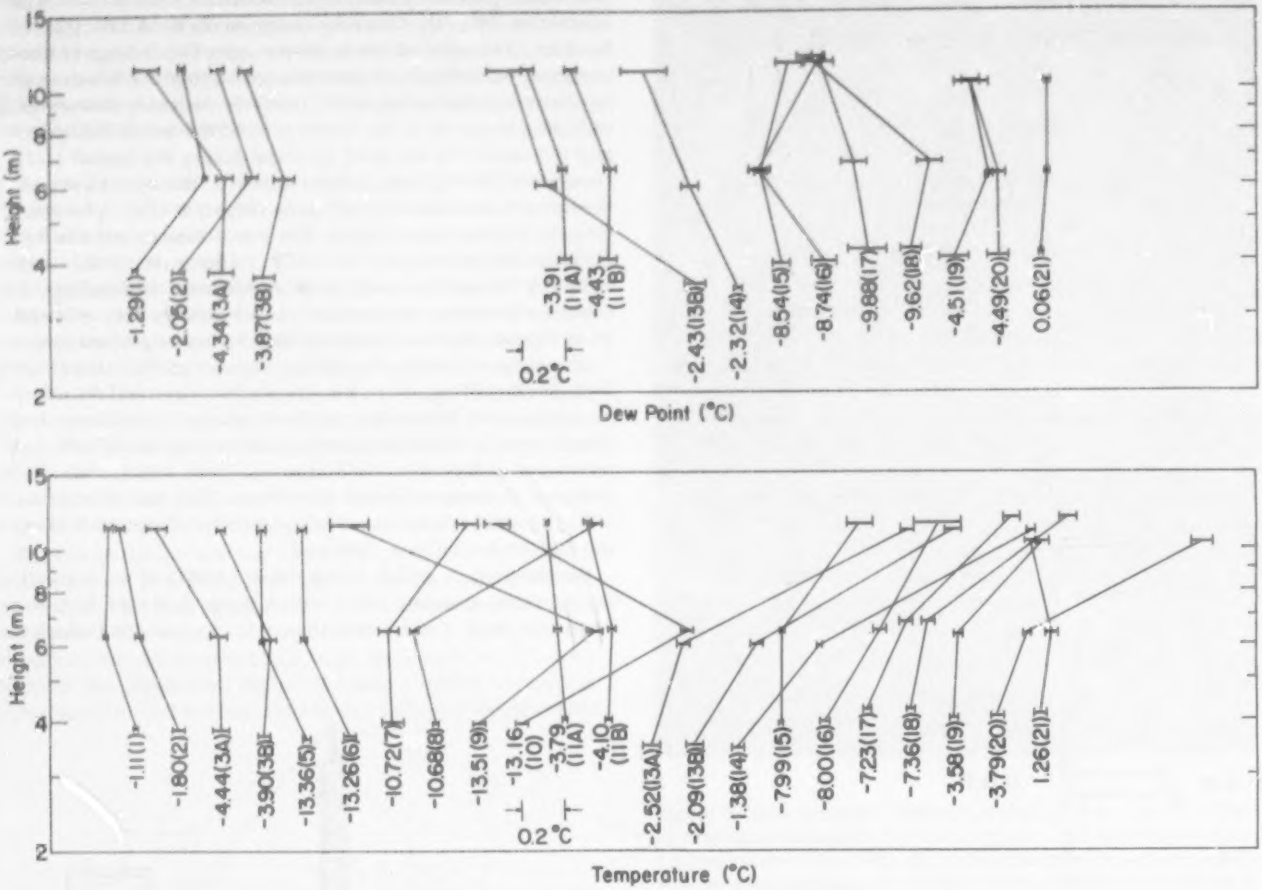

Figure 2. Some profiles of measured temperature (a) and dew point (b). The error bars indicate plus and minus one standard deviation. The numbers under the profiles indicate the measured value at the lowest level and the run number (in parentheses).

and physical oceanographers on the expedition used winches located on the starboard side of the *Somov* for their casts, they preferred to have the ship crosswind with the wind from starboard. Therefore we ran our boom out from the rear, starboard corner of the helicopter deck and then rotated our instrument mast into the wind. The ship thus did not disturb the airflow at our instruments very much, and all three measurement programs—boundary layer, biology, and physical oceanography—could go on simultaneously.

Our profiling mast was instrumented at three levels. Each level had a General Eastern 1200MPS system for measuring temperature and dew point and a Gill propeller anemometer, made by the R. M. Young Company, for measuring wind speed. A wind vane at the top of the mast was used for orienting the instruments into the wind.

Figure 2 shows some of the temperature and dew-point profiles we collected. These profiles are rather complex because we encountered a variety of surface conditions. Andreas (1982) and Andreas, Williams, and Paulson (1981) have shown that when an atmospheric flow encounters a change in surface moisture or temperature, an internal boundary layer—a region near the surface in which the flow is affected by the new surface—develops according to

$$h/z_T = 1.31\,(X/z_T)^{0.8},$$

where X is the fetch over the new surface, h is the maximum height at X that is affected by the new surface, and z_T is the scalar roughness length, that is, the height at which the extrapolated temperature or humidity profile equals the surface value of the variable. With z_T typically 0.025 centimeter over water and with the height of our highest profiling level about 11.5 meters, this equation shows that if the surface change was less than 120 meters upwind of our mast, the upper instruments were above the internal boundary layer and so were not influenced by the new surface. For longer fetches, all instrument levels were within the internal boundary layer.

Since we know this cutoff fetch, we can define three types of surface regimes and their corresponding profile runs:

- Ice—at least 90 percent ice cover upwind of the instrument mast: runs 3A, 3B, 7, 8, 9, 10, 15, 16;
- Open water—open water for at least 300 meters upwind: runs 11A, 11B, 13A, 13B, 14, 17, 18, 21; and
- Ice and water—roughly 50 percent ice cover for at least 100 meters upwind, at least 90 percent ice beyond: runs 1, 2, 5, 6, 19, 20.

Surface conditions generally control the shapes of the temperature and dew-point profiles. For example, although the dew-point profiles for runs 11A, 11B, 13B, and 14 are consistent with our categorizing of them as "open water" runs, 11A and 11B show unstable temperature profiles while 13A, 13B, and 14 have very stable profiles. This is because for the former runs the air temperature was lower than the water temperature (about −1.9°C); for the latter runs it was nearly the same or higher (compare Andreas et al. 1979).

We wish to acknowledge the support of National Science Foundation grant DPP 80-06922. John Rand designed and built the surface-layer-profiling boom, and Stephen Ackley assisted with the measurements. Alexander Makshtas was responsible for the hourly meteorological observations. Ed Lysakov helped with Airsonde operations. Stanislav Bobrov and Valerii Posazhennikov of the *Somov* made the MicroCORA soundings.

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Ocean sciences

Frontal baroclinic instability of the Antarctic Front Zone

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ARA *Islas Orcadas* cruise 17-78 took place between 2 September and 14 October 1978 (see Inoue and Ichiye 1980). Temperature and salinity profiles taken at station 7, located south of the Antarctic Front Zone in the Drake Passage, show that interleaving structures were conspicuous in the upper layer, as seen in figure 1. The pair of stations 6 and 7 produced an unusually strong geostrophic current of 63 centimeters per second, assuming that there is no motion at the 1,500-decibar level (about 1,500 meters) (figure 2). The interleaving profiles may have been caused by convective processes, by advection of different water masses at different levels, or by other processes. However, the example of station 7 suggests that the cause was baroclinic instability coupled with horizontal shear instability, since from 100 meters to 900 meters the density at station 7 increased almost linearly with depth, by 0.000413 grams per cubic centimeter, and the geostrophic speed between stations 6 and 7 decreased linearly with depth, by 29 centimeters per second.

Eady (1949) examined baroclinic instability of the geostrophic basic flow that has a speed decreasing linearly with depth generated by a density distribution increasing linearly downward (see also Pedlosky 1971). However, in Eady's model the basic flow is bounded by two parallel vertical walls. The instability occurs in a certain range of the wave number (inverse of the wavelength) of the perturbation propagating in the direction of the flow. This range corresponds to the presence of an imaginary part of the frequency in the frequency-wave number curves which indicate a possible period (inverse of frequency) for a certain wave length of the disturbance. The imaginary part has a maximum at a certain wave number, which may excite perturbation fastest and thus correspond to the most probable scale of the perturbation. The Eady model may not be applicable to the Antarctic Front Zone, where there is no apparent vertical boundary.

A new model has been developed, one in which the basic current decreases exponentially with distance from a horizontally uniform flow (Ichiye 1982). In this model the perturbations have cellular structures in the vertical direction. Further, the instability is strongly excited by resonance of baroclinic instability coupled with instability of horizontal shear, as manifested by an infinite amplification factor at certain wave numbers, though the infinite become finite by including a dissipation mechanism. Figure 3 shows the amplification factor for the perturbation wave number scaled with the distance $L = NHf^{-1}$, where N is the Väisälä frequency, H is the thickness of the layer, and f is the Cariolis frequency. The factor A is a distance scaled with L, in which the basic flow decreases to the e-times of the maximum value (e-folding distance). The mean value of L at stations 6 and 7 is 21 kilometers between 100 and 900 meters.

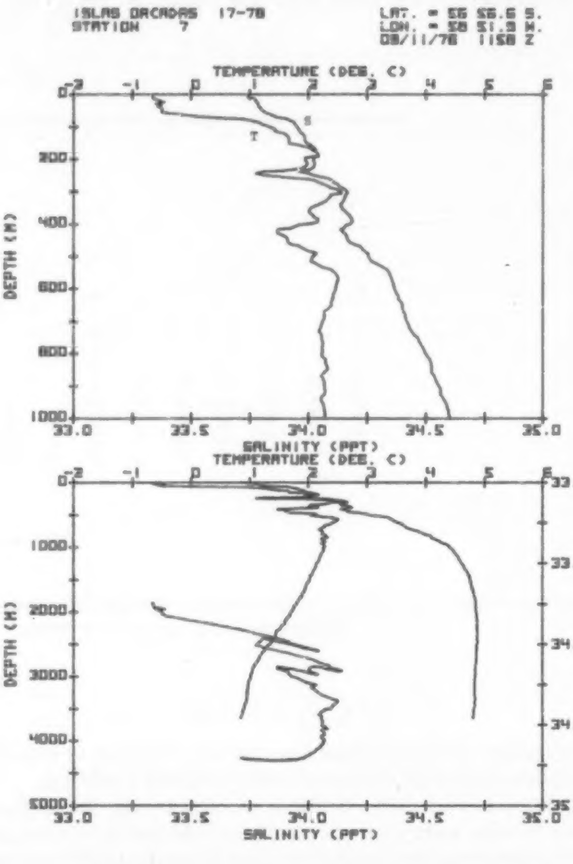

Figure 1. Temperature and salinity profiles down to 1,000 meters (upper panel) and down to 4,000 meters with temperature-salinity curve (lower panel), station 7, *Islas Orcadas* cruise 17-78. PPT = parts per thousand.

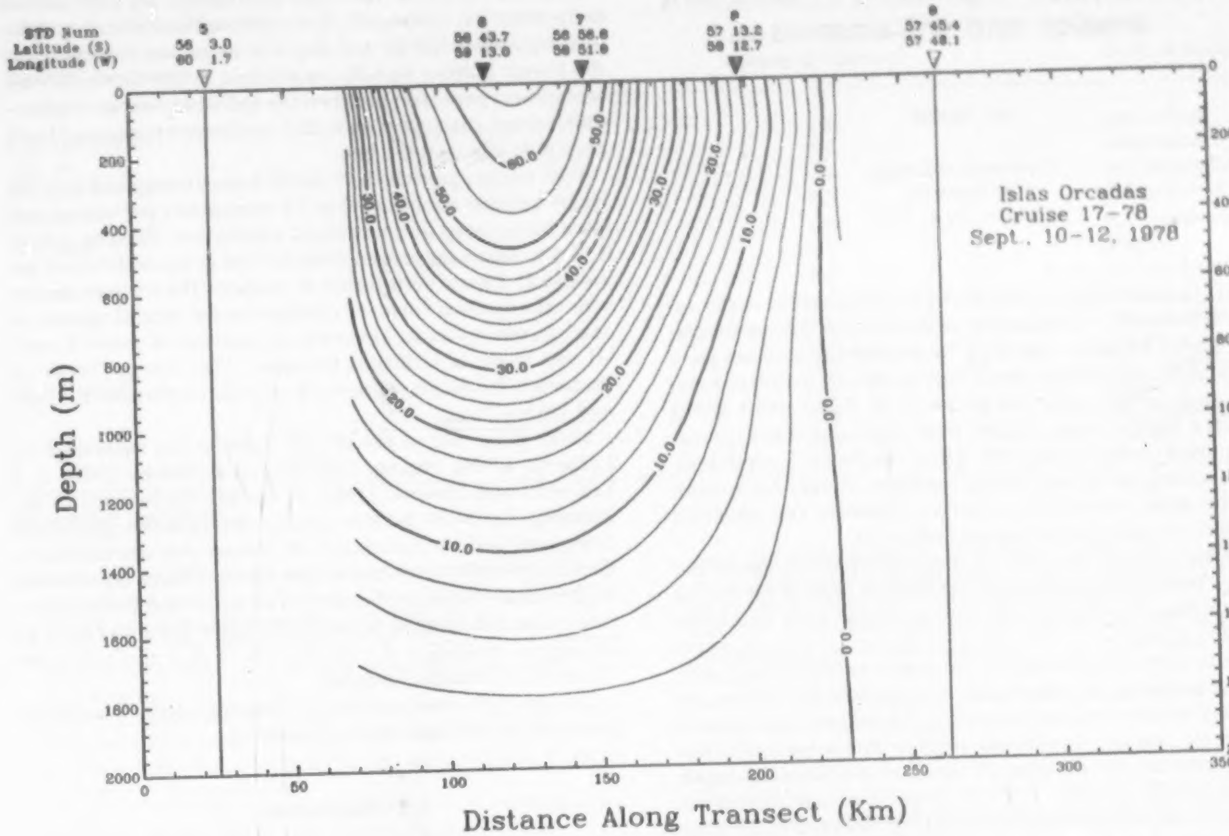

Figure 2. Vertical cross section of geostrophic speed (in centimeters per second) in the Drake Passage, assuming there is no motion at the 1,500-decibar level (about 1,500 meters), from data taken on *Islas Orcadas* cruise 17-78.

Thus the *e*-folding distance should be less than 5 kilometers in order that the perturbation may have cellular structures. This suggests that the interleaving structures could not be present at station 8, as indicated by the data.

The work on the *Islas Orcadas* 17-78 data was supported by National Science Foundation grant DPP 79-09258, and the work on instability was supported by Office of Naval Research contract N00014-80-C-0113.

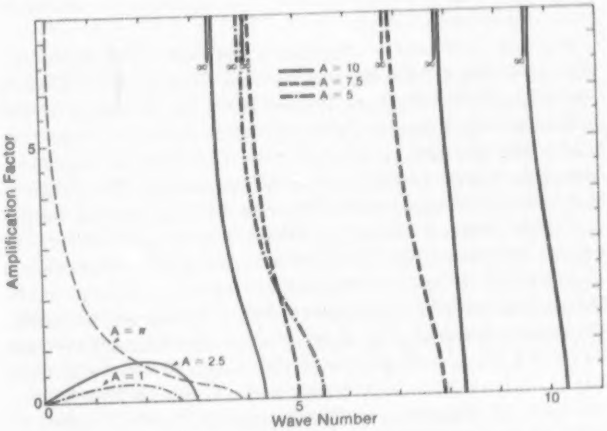

Figure 3. Amplification factor (scaled with f^{-1}) against perturbation wave number (scaled with $L = NHf^{-1}$). (See text for explanation of abbreviations.) *A* is the scaled *e*-folding distance of the mean flow from the maximum current. The infinity notation (∞) indicates the wave number at which the amplification factor becomes infinite.

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Role of benthic organisms in sediment erosion and entrainment

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An understanding of conditions by which sediment transport is initiated is fundamental to the study of paleoceanography. Earlier workers examining the relationship between grain size and current velocity based their studies on distributions of uniformly sorted, spherical grains or on distributions falling within a narrow range of grain sizes. Although this approach has proved useful in interpreting fluvial systems in which sediment undergoes sorting during transport, it does not account for the ability of marine currents to winnow and transport texturally homogeneous marine sediments.

Antarctica presents a unique environment where glacial and glacial marine sediments have undergone little or no sorting prior to their deposition in the marine environment. One of the most puzzling questions in studying modern sediments on the antarctic continental margin is the degree to which these sediments are being reworked and resedimented by bottom currents. The best available oceanographic information suggests that these bottom currents move rather slowly (generally less than 15 centimeters per second). However, existing data suggest that this sorting process occurs at much greater current velocities (>40 centimeters per second). For this reason, the available data relating flow parameters to sediment erosion and transport were seriously questioned. The existing data have overlooked the role of benthic organisms in initiating sediment erosion under low-velocity current conditions. The goal of this research is to assess the role of benthic organisms in sediment erosion and entrainment.

The action of benthic organisms has been documented by various workers (Nowell, Jumars, and Eckman 1981; Rhoads and Young 1970; Yingst and Rhoads 1978). The feeding activities of benthic organisms have been shown to decrease compaction and to increase both surface water content and bed roughness, as well as to cause a resuspension of fine sediment. The distribution of benthic organisms on the antarctic continental margin has also received attention. Dense benthic populations of sponges and bryozoans having a biomass of 400–500 grams per square meter (El-Sayed 1971) are known to occur on the antarctic continental shelf (100–500 meters). Below 500 meters, the sessile population is replaced by vagrant organisms having a biomass of 1.3–2.8 grams per square meter (El-Sayed 1971), of which the Ophiuroidea (brittle stars) locally may account for 75 percent of the biomass (Dearborn 1977) (see figure).

To examine the role of organisms, a series of experiments was performed in a recirculating flume in which an originally unsorted bed was continuously mixed so as to mimic bioturbation. Currents in the range of 1.5 to 20.0 centimeters per second were used, as this represented the range of current velocities measured to date near the antarctic seafloor. Textural data of the suspended, intermittent suspension, and traction loads were determined by methods outlined by Anderson and Kurtz (1979).

Data compiled from the flume experiments are summarized in the table. It is noteworthy that, with mechanical mixing of the bed, material in the silt and clay size range was transported at the lowest current velocity established in the flume (1.5-2.0 centimeters per second). When the sediment was not mechanically mixed, currents of up to 20.0 centimeters per second had a negligible effect on the bed.

With mixing, particles 3.75 to 4.00 ϕ were winnowed from the bed at velocities of from 5.0 to 7.0 centimeters per second and were transported in intermittent suspension. Particles 3.00 to 3.75 ϕ in size were eroded from the bed at 9.0 centimeters per second and were transported in traction. The increase in current velocity from 7.0 to 9.0 centimeters per second appears to mark an energy transition involving both size of material eroded and mode of sediment transport. This energy "break" is commonly found in sediments from piston cores from the Ross and Weddell Seas.

Mean grain size of the silt size fraction has been used by Ledbetter (1979), Huang, Ledbetter, and Watkins (1982), and Ledbetter and Ellwood (1982) to identify fluctuations in the intensity of antarctic bottom water (AABW) related to glacial and interglacial periods (associated with increased or decreased production of AABW). However, results from my flume experiments suggest that efficiency of mixing is an important factor to consider when interpreting textural data. Mean grain size may not be only an indication of paleovelocity; it may also reflect the efficiency of biological mixing.

This research was supported by National Science Foundation grant DPP 81-16623 to John B. Anderson.

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Bottom photograph showing brittle stars, at 63°02′S 52°03′W; water depth, 1,200 meters. Note that the bottom sediment consists of a lag deposit; the fine sediment was eroded by the action of benthic organisms.

Summary of data from a series of flume experiments

Sediment component	Size range (ϕ)	Minimum velocity for entrainment (cm/sec)	Mode of transport
Clay and fine silt	7.00–10.00	1.5	suspension
Fine silt	6.25–7.00	7.5	suspension
Clay and fine silt	6.25–10.00	1.5	int. suspension*
Coarse silt	4.25–6.00	2.0	int. suspension
Fine sand	3.50–4.00	5.0	int. suspension
	3.00–3.50	9.0	traction
Medium sand	2.00–3.00	13.0	int. suspension
		11.0	traction
	1.00–2.00	16.0	int. suspension
		13.0	traction
Coarse sand	−.50–1.00	18.0	int. suspension
		13.0	traction
	−1.00–−.50	>20.0	int. suspension
		16.0	traction

*Intermittent suspension.

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Heat flow measurements in the Scotia Sea collected during *Atlantis II* cruise 107-6

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Cruise 107, leg 6, of the R/V *Atlantis II* left Punta Arenas, Chile, on 4 March 1980 and arrived at Cape Town, South Africa, on 7 April 1980. Principal shipboard programs included rock dredging under the direction of H. J. B. Dick, chief scientist, sediment coring under the direction of B. Corliss (Woods Hole Oceanographic Institution), heat flow measurements in the Scotia Sea under the direction of V. Zlotnicki and W. Loy, and underway geophysical data collection (12- and 3.5-kilohertz echo-sounding, air-gun profiling, magnetics, and gravity).

The east Scotia Sea is an actively spreading marginal sea that lies behind the active South Sandwich Islands arc (Barker 1972). Oceanic crust of the South American plate is being subducted in a westward direction beneath the South Sandwich arc and the east Scotia Sea at the South Sandwich Trench. Barker (1972) identified magnetic anomalies generated by seafloor spreading in the east Scotia Sea, thus allowing estimation of the age of the ocean floor. Heat flow measurements can be used to understand the thermal regime of the oceanic crust and the influence of the cool subducted slab on active seafloor spreading in a marginal basin only if the age of the underlying oceanic crust is known. The heat flow program was aimed at correlating heat flow and age in this marginal basin and comparing these relationships with those found for normal oceanic crust.

On the *Atlantis II* 107-6 cruise, a 300-kilometer survey was run prior to the heat flow investigation. This survey produced

Heat flow values in the South Atlantic

Station number	Position	Depth (meters)	Conductivity (mcal/°C cm)[a]	Gradient (m°C/cm)[b]	Heat flow (μcal/cm^2 sec)[c]
1	56°13.20'S 32°21.3'W	3,262	1.79	N.D.[d]	N.D.
2	56°21.5'S 32°44.7'W	3,174	1.69	N.D.	N.D.
3	56°18.92'S 32°46.88'W	3,124	1.56	N.D.	N.D.
4	56°16.81'S 32°45.05'W	3,116	1.69	N.D.	N.D.
5	56°17.62'S 32°38.86'W	3,223	1.68	1.07	1.80
6	56°17.38'S 32°41.29'W	3,273	2.03	0.69	1.40
7	56°16.94'S 32°38.41'W	3,260	1.66	0.15	0.25
8	55°16.5'S 22°09.7'W	4,050	1.71	1.07	1.83
9	54°50.5'S 17°58.5'W	4,140	1.59	0.94	1.49

[a] mcal/°C cm = microcalories per °centigrade-centimeter.

[b] m°C/cm = milli-°centigrade per centimeter.

[c] μcal/cm^2 sec = microcalories per centimeter squared-second.

[d] N.D. = no data.

excellent magnetic anomaly lineations, alined nearly north-south, as expected, from the westward subduction of oceanic crust beneath the Sandwich arc. These anomalies can be traced on seven crossings over a distance of 40 kilometers, and they are readily matched to those identified by Barker (1972). The inferred spreading rate in the east Scotia Sea varies between 5 to 6 centimeters per year 4 million years ago and 7 to 9 centimeters per year at present. The survey had been planned for an area believed to have an adequate sediment cover, a necessary condition for reliable heat flow measurements. However, ice conditions forced us to work north of the desired area. All the heat flow stations had to be taken in an area of isolated sediment ponds surrounded by unsedimented basement highs. This situation usually leads to low heat flow readings, both because of refraction and, more importantly, because the thin sediment cover does not prevent convective heat flux through the young oceanic crust (Williams et al. 1974). For normal oceanic crust of an age of 3–4 million years, the conductive heat flow is expected to be 5.6–6.8 heat flow units (HFU). The values measured at the three stations in the east Scotia Sea where measurements were obtained were much lower, between 0.25 and 1.8 HFU, due to this environmental effect (see table). Four other stations were unsuccessful due to instrument failure.

Two additional heat flow values were taken on this cruise outside the east Scotia Sea. Station 8 was located just east of the South Sandwich Trench on the South American Plate. A value of 1.83 HFU was found, which is slightly high if the crust was formed at the mid-Atlantic ridge approximately 65 million years ago. The last station produced a value of 1.49 HFU, which is within 10 percent of what would be expected on crust 50 million years old.

The results of this cruise proved that heat flow measurements can be made in marginal basins on crust of a known age. The eastern side of the active spreading center had a much more uniform sediment cover on crust of approximately the same age. A subsequent cruise (Lawver et al. 1981) took measurements there and found substantially higher heat flow values on crust of the same age. This proved that the low heat flow values measured on the *Atlantis II* 107-6 cruise in the east Scotia Sea are a result of extensive hydrothermal circulation in inadequately sedimented crust and are not due to any processes peculiar to marginal basins.

This cruise was supported by National Science Foundation grant DPP 78-19279 to the Massachusetts Institute of Technology.

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Oligocene-Miocene diatom biostratigraphy from the equatorial to the antarctic Pacific

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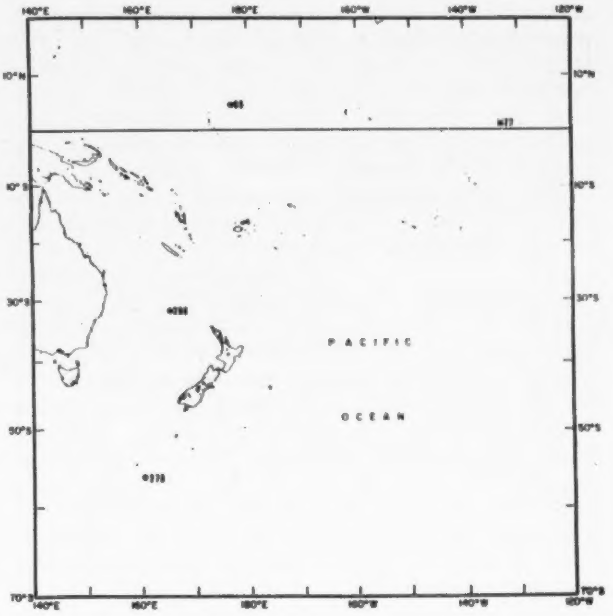
Diatoms play a significant role in interpreting the geological history of the antarctic area. This is due to (1) the great abundance and diversity of diatoms in that region, (2) the absence of calcareous microfossils south of the Polar Front, and (3) the low abundance and diversity of radiolarians in the antarctic region. Because of the absence and low abundance of these microfossils, a refined diatom stratigraphy is essential to antarctic marine research.

Abundant data on the stratigraphic ranges of Neogene diatoms are available, and a refined Neogene diatom zonation exists for the circumantarctic region (Weaver and Gombos 1981). However, Paleogene diatom stratigraphy is still in a developmental stage.

The development of a biostratigraphic zonation must progress through several phases before reliable ages can be determined. Initially, zones are defined with easily identifiable, widespread, and short-lived species. Next, these zones must be tested in other regions to determine their degree of utility as regional correlation tools. Limitations are placed on zones that are not regionally applicable, and occasionally the zones are redefined using biostratigraphic datums that are regionally recognizable.

This study provides the initial testing of a Paleogene stratigraphy developed in the southwest Atlantic. The purpose is to determine the applicability of this zonation in other regions of the Southern Hemisphere. Twelve diatom biostratigraphic zones, from the upper Eocene through the lower Miocene, were defined by Gombos and Ciesielski (in press) on the basis of sediments from the southwest Atlantic recovered during Deep Sea Drilling Project (DSDP) leg 71. The present study tests the applicability of seven of these zones in the Pacific Ocean from the Equator to the Antarctic. Four DSDP sites are examined in this investigation: Site 278 in the high latitudes, east of Macquarie Ridge; Site 206 in the middle latitudes, east of Lord Howe Rise; and Sites 65 and 77 near the Equator (figure 1). All seven zones are recognized in at least one of the sites examined in this study. Limitations are placed on several zones, as their application in the southern Pacific appears to be latitudinally restricted; the *Triceratium groningensis* and *Pyxilla prolungata* Zones are recommended for use in high latitudes only.

This study examines younger material than did Gombos and Ciesielski's study. Three new zones and one from Schrader (1976) are correlated to the youngest zone of Gombos and Ciesielski, thereby extending the coverage of their zonation (figure 2). Species present in both the equatorial and antarctic regions of the Pacific are used to define these new zones to avoid latitudinal restriction of their use. In many cases, modifications of pre-existing zones were required.


140°E
160°E
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160°W
140°W
120°W
10°N
10°S
30°S
50°S
70°S
65
77
206
278
PACIFIC
OCEAN

Figure 1. Location of Deep Sea Drilling Project sites examined in this study.

The *Denticulopsis nicobarica* Zone was originally defined by McCollum (1975), using the lowest occurrence of *D. nicobarica* to define the base of the zone. This study redefines this zone by using the highest occurrence to define the upper boundary. The *D. nicobarica* Zone used here is younger than originally defined by McCollum.

The *Coscinodiscus lewisianus* Zone is used as originally defined by Schrader (1976). The base of this zone was redefined by Weaver and Gombos (1981) using the highest occurrence of *Nitzchia maleinterpretaria*. I prefer Schrader's original definition because *N. maleinterpretaria* was not encountered in the equa-

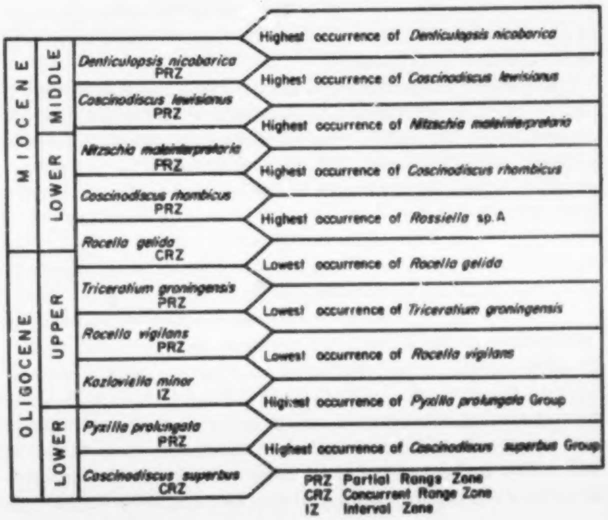
MIOCENE
MIDDLE
LOWER
OLIGOCENE
UPPER
LOWER
Denticulopsis nicobarica PRZ
Coscinodiscus lewisianus PRZ
Nitzschia maleinterpretaria PRZ
Coscinodiscus rhombicus PRZ
Rocella gelida CRZ
Triceratium groningensis PRZ
Rocella vigilans PRZ
Kozloviella minor IZ
Pyxilla prolungata PRZ
Coscinodiscus superbus CRZ
Highest occurrence of *Denticulopsis nicobarica*
Highest occurrence of *Coscinodiscus lewisianus*
Highest occurrence of *Nitzschia maleinterpretaria*
Highest occurrence of *Coscinodiscus rhombicus*
Highest occurrence of *Rossiella* sp. A
Lowest occurrence of *Rocella gelida*
Lowest occurrence of *Triceratium groningensis*
Lowest occurrence of *Rocella vigilans*
Highest occurrence of *Pyxilla prolungata* Group
Highest occurrence of *Coscinodiscus superbus* Group
PRZ Partial Range Zone
CRZ Concurrent Range Zone
IZ Interval Zone

Figure 2. Diatom zones and the datums that define them.

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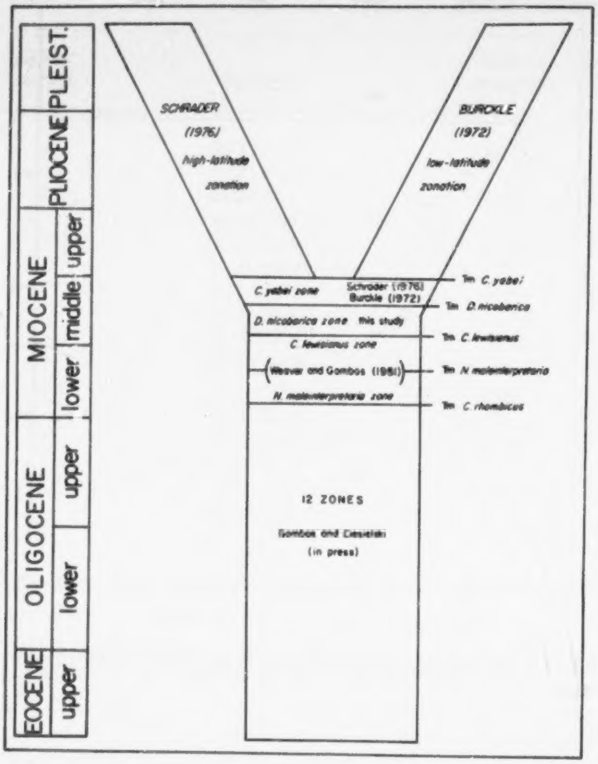

PLEIST.
PLIOCENE
MIOCENE
upper
middle
lower
OLIGOCENE
upper
lower
EOCENE
upper
SCHRADER
(1976)
high-latitude
zonation
BURCKLE
(1972)
low-latitude
zonation
C. yabei zone
Schrader (1976)
Burckle (1972)
D. nicobarica zone this study
C. lewisianus zone
(Weaver and Gombos (1981))
N. maleinterpretaria zone
Tm C. yabei
Tm D. nicobarica
Tm C. lewisianus
Tm N. maleinterpretaria
Tm C. rhombicus
12 ZONES
Gombos and Ciesielski
(in press)

Figure 3. Correlation of the zones applied in this study to Schrader's (1976) antarctic zones and Burckle's (1972) equatorial zones.

torial Pacific sites and the zone as defined by Weaver and Gombos could not be recognized.

The *Raphidodiscus marylandicus* Zone was originally defined by Schrader (1976) using the lowest occurrence of *R. marylandicus* to define the base of the zone. In this study, the highest occurrence of *R. marylandicus* defines the upper boundary while the lowest occurrence of *Denticulopsis nicobarica* defines the base of the zone. This zone, as defined here, is younger than originally defined by Schrader.

The *Synedra jouseana* Zone is the only new zone proposed in this study. It is an interval or gap zone between the highest occurrence of *Coscinodiscus rhombicus* and the lowest occurrence of *Denticulopsis nicobarica*. This zone is named after *S. jouseana*, which is consistently present in the interval between the two marker species. The base of the *Synedra jouseana* Zone is coincident with the top of the *Coscinodiscus rhombicus* Zone. This coincidence provides the connection between the zones proposed by Gombos and Ciesielski (in press) and those proposed in this study.

The top of the *Denticulopsis nicobarica* Zone is coincident with the base of the *Denticulopsis dimorpha* Zone of Schrader (1976) (figure 3). This enables correlation of the zonation applied in this study with the high-latitude, post-middle Miocene zones of Schrader, which were adopted from McCollum (1975).

The zonation used in this study can be linked to the equatorial Pacific zonation of Burckle (1972) by way of Schrader's (1976) *Coscinodiscus yabei* Zone. The base of the *C. yabei* Zone (Schrader 1976), is coincident with the top of the *Denticulopsis dimorpha* Zone (Schrader 1976), which is correlated to the zonation used here, as discussed earlier. The *Coscinodiscus yabei* Zone is also used by Burckle (1972) in his equatorial Pacific zonation. The highest occurrence of *C. yabei* defines the top of the *C. yabei* Zone in both Schrader's (1976) high-latitude zonation and Burckle's (1972) equatorial zonation. The fact that both zonations use the same datum to define the top of the *C. yabei* Zone enables a correlation of Burckle's (1972) zones to those applied in this study. Correlating Burckle's zones to those used in this study requires the use of Schrader's *Denticulopsis dimorpha* Zone as a link.

With the addition of post-middle Miocene zones from Schrader (1976), McCollum (1975), and Burckle (1972) to the zonation developed herein and the 12 zones of Gombos and Ciesielski (in press), a composite diatom biostratigraphic zonation from the late Eocene to the Recent is proposed.

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Petrology of Ross Sea basal tills: Implications for antarctic glacial history

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The glacial history of the Ross Sea has long been a subject of debate. In an attempt to shed light on the glacial history of the western Ross Sea, piston core samples collected during the Deep Freeze 80 cruise of the USCGC *Glacier* were studied. Three major questions were addressed: Does basal till exist in the western Ross Sea? If so, what was the source of sediments that make up these basal tills? What does knowledge of sediment source tell us about the glacial history of the western Ross Sea?

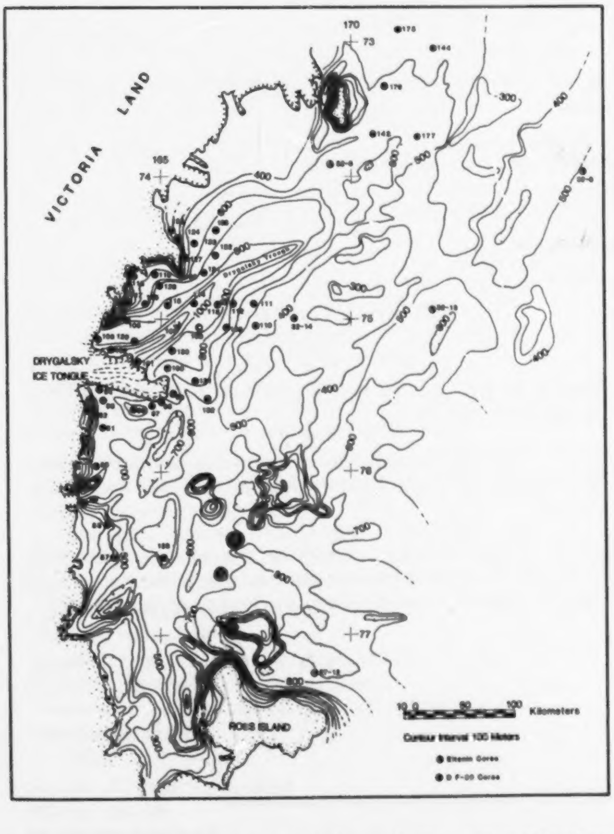

Figure 1. Location of the primary study area in the western Ross Sea, locations of cores examined in this study (except central Ross Sea cores), and bathymetry of the western Ross Sea. Note that deep troughs originate near the outlets of glaciers from East Antarctica. Depth data were compiled from H.O. Chart 29012, Ross Sea, 1978 edition (Defense Mapping Agency, Hydrographic Office, Washington, D.C.) and from Deep Freeze 80 depth records from the USCGC *Glacier*.

The primary study area encompassed the Ross Sea west of 170°E, south of Coulman Island, and north of the Ross and McMurdo Ice Shelves (figure 1). The study area is bounded on the west by the Transantarctic Mountains, through which large outlet glaciers flow, draining the massive east antarctic ice sheet. Where east antarctic outlet glaciers flow into the Ross Sea, large floating ice tongues, such as the Drygalski Ice Tongue, may form. Bathymetric maps of the present seafloor reveal that submarine troughs originate at or near the debouchments of large outlet glaciers and bend north-northwest as they enter the Ross Sea (figure 1).

Much of this study concentrated on the sedimentology and basal till petrology in the Terra Nova Bay region because of the excellent core coverage there. Three major sediment types, siliceous muds, sands, and diamictons, were found in the western Ross Sea. On the basis of the criteria of Anderson and associates (1980) and Kurtz and Anderson (1979), the diamictons were further subdivided into three types: compound glacial marine sediments, mass flow diamictons, and basal tills.

With the aim of reconstructing paleoglacial-flow paths, basal tills from the western Ross Sea, identified in this study, and basal tills from the south-central Ross Sea, identified by Anderson and associates (1980), were petrologically analyzed. Heavy mineral and lithic petrologic provinces were defined, and correlations to rock outcrops in Victoria Land and Marie Byrd Land were made.

Petrologic analyses indicate that three distinct petrologic provinces exist in the western Ross Sea and that four petrologic provinces exist in the south-central Ross Sea (figure 2). It is interesting to note that the boundaries between petrologic provinces parallel bathymetric trends and, in the south-central Ross Sea, lie perpendicular to iceberg drift paths.

Minerals and lithologies of province 1 were found to correspond well to metamorphic rocks between Reeves Glacier and Campbell Glacier. The boundary between provinces 1 and 2 is sharply defined and coincides closely with the geologic boundary between dominantly metamorphic rock to the north and dominantly granitic rock to the south near the northern edge of Reeves Glacier. No good correlation between province 2 minerals and lithologies and coastal geology was found. It is likely, however, that source rocks for province 2 lie undiscovered beneath the ice-covered terrain between Mawson Glacier and David Glacier. Minerals and lithologies of province 3 correlate well with the broad zone of Beacon Group rocks north of Byrd Glacier and south of Mawson Glacier.

Correlations for provinces 4, 5, 6, and 7 were more general because of the greater petrologic homogeneity of basal tills in the central Ross Sea. However, minerals and lithologies of province 4 correspond well to the mixed metamorphic and granitic terrain between Shackleton Glacier and Byrd Glacier. Minerals and lithologies of provinces 5 and 6 probably were derived from metamorphic terrain beneath the west antarctic ice sheet. Minerals and lithologies of province 7 correlate with granitic and low-grade metasedimentary rocks in the Ford Ranges of Marie Byrd Land.

Results of this study indicate that basal till exists in the western Ross Sea as far north as Coulman Island. The presence of basal till indicates that ice has advanced and grounded in the western Ross Sea. Petrologic data indicate that this ice flowed from both East Antarctica and West Antarctica. Studies of this sort not only serve to reconstruct paleoglacial-flow paths, but also may be used as a tool in geologic mapping of the ice-bound antarctic continent.

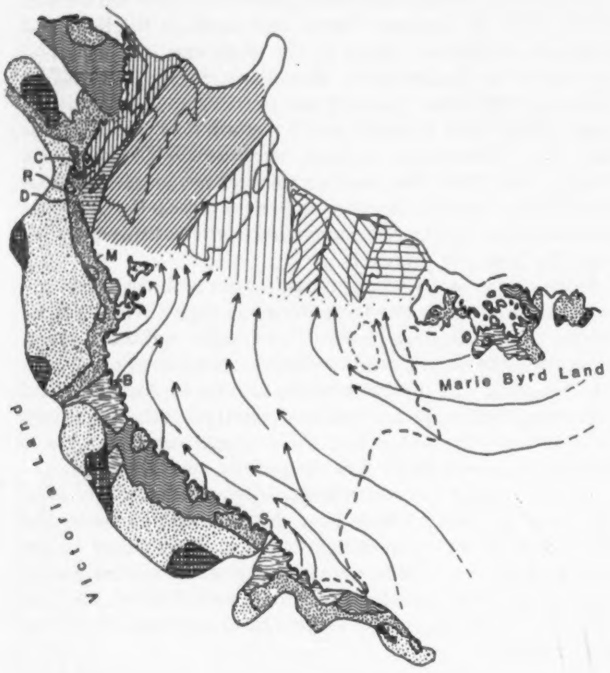
C
R
D
M
B
S
Marie Byrd Land
Victoria Land
LEGEND
VICTORIA LAND
McMurdo Volcanics
Ferrar Group
Beacon Group
Granitic Rocks
Low-grade Metasedimentary Rocks
Low- to Medium-grade Metasedimentary Rocks
MARIE BYRD LAND
Cenozoic Volcanics
Granitic Rocks
Jurassic Volcanics
Low-grade Metasedimentary Rocks and Sedimentary Rocks
High-grade Metamorphic Rocks and Intrusives
Province 1
Province 2
Province 3
Province 4
Province 5
Province 6
Province 7

Figure 2. Petrologic provinces 1 through 7 (from west to east) for Ross Sea basal tills. Arrows indicate modern ice-flow paths in the Ross Ice Shelf (after Hughes 1975). Generalized geology after Craddock (1972). Water depth contours are shown for 500 and 1,000 meters. Abbreviations: B = Byrd Glacier, C = Campbell Glacier, D = David Glacier, M = Mawson Glacier, R = Reeves Glacier, and S = Shackleton Glacier.

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Preliminary results of microfossil analyses of Amundsen Sea sediment cores

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One of our long-term research goals is to determine the former extents of grounded ice on antarctic continental shelves. This article reports our preliminary findings from analyses of diatoms in two sediment cores (DF81-6 and DF81-7) collected from the outer continental shelf in the Amundsen Sea (table) by one of us (J.B.A.).

The top 2 to 10 centimeters of each core had a high water content at the time of recovery and consisted of mud or sandy, silty clay. Beneath this uppermost layer, both cores consist of overcompacted, unstratified diamicton. This basic stratigraphy, of mud overlying a diamicton, is similar to that of Ross Sea cores we analyzed previously (Kellogg, Truesdale, and Osterman 1979), suggesting the possibility that the layers in Amundsen Sea cores might have formed under conditions similar to those documented for deposition of Ross Sea sediments (Anderson et al. 1980; Kellogg, Osterman, and Stuiver 1979; Kellogg and Truesdale 1979).

Preliminary sampling was designed to test the validity of this supposition. We sampled the top centimeter of each core and took samples from near the base of the diamicton. Standard diatom preparations were made following the procedure of Schrader (1974). Our attempts to obtain quantitative species census data (counts of more than 100 specimens for each sample) were unsuccessful because of the extremely low abundances of diatoms in the samples, despite exhaustive analysis of each slide (and, in most cases, of multiple slides for each sample).

Our diatom census data are presented in the table. A total of 17 taxa were identified (some tentatively). Of these taxa, seven are marine species and six are nonmarine species. No species consistently dominates in either the upper or lower sediment layer. Nevertheless, there is a clear tendency for marine species to occur primarily in the upper layer. Nonmarine species occur in both units. Siliceous sponge spicules occur in all samples,

Diatom census data from Amundsen Sea sediment cores DF81-6 and DF81-7

Taxon	Upper layer[a]		Lower layer[b]		Remarks
	DF81-6	DF81-7	DF81-6	DF81-7	
Charcotia actinochilus (Ehrenberg) Hustedt (1958)	1	0	0	0	marine
Cyclotella compta (Ehr.) Kützing (1849)	1?	2	0	2	nonmarine
Cyclotella stelligera Cl. & Grun. *in* v.H. (1881)	0	0	0	3	nonmarine
Cyclotella Kützing (1833) sp.	0	0	1?	1?	
Grammatophora Ehrenberg (1839) sp.	0	0	0	1?	
Melosira distans (Ehrenberg) Kützing (1844)	0	0	0	1	nonmarine
Melosira italica var. *subarctica* Müller (1906)	5	0	0	0	nonmarine
Melosira sol (Ehrenberg) Kützing (1849)	0	0	0	1	marine
Navicula deltaica Kellogg (1980)	1	0	0	0	nonmarine
Navicula gelida Heiden & Kolbe (1928)	1?	0	0	0	marine
Nitzschia kerguelensis (O'Meara) Hasle (1972)	0	2	0	0	marine
Nitzschia obliquecostata (van Heurck) Hasle (1972)	0	1	0	0	marine
Nitzschia sublineata (Hustedt) Hasle (1972)	0	1?	0	0	marine
Opephora Petit (1888) sp.	0	0	1	0	
Tabellaria flocculosa (Roth.) Kützing (1844)	0	0	6?	0	nonmarine
Tabellaria quadriseptata Knudson (1952)	1	0	1	0	nonmarine
Thalassionema nitzschioides Grun. *in* v.H. (1881)	0	1?	0	0	marine
Other (unidentified)	0	0	0	1	
Total	10	7	9	10	
Number of transects examined	15	20	20	37	
Sponge spicules	P[c]	P	P	P	
Radiolarian fragments	NP[d]	NP	NP	P	

Note: Core DF81-6 located at 71°16′S 110°16′W; water depth, 450 meters; length, 148 centimeters. Core DF81-7 located at 71°15′S 109°00′W; water depth, 470 meters; length, 232 centimeters.

[a] Both cores sampled at 0–1 centimeter.

[b] Core DF81-6 sampled at 140–141 centimeters; core DF81-7 sampled at 220–221 centimeters.

[c] P = present.

[d] NP = not present.

and fragments of an unidentified radiolarian were noted at the base of the diamicton in DF81-7.

The diatom assemblage in Amundsen Sea cores DF81-6 and DF81-7 is strikingly different from any we have previously studied in the Ross Sea (Kellogg and Kellogg 1981; Kellogg and Truesdale 1979) or the Weddell Sea (D. E. Kellogg unpublished data, University of Maine at Orono, 1982). We stress again that our analyses were exhaustive (more than 2 days were spent examining duplicate slides from each sample), yet no sample contained as many as 11 specimens. This is an extremely depauperate flora. All marine species encountered here were also found in Recent sediments (unit A) of Ross Sea cores (Truesdale and Kellogg 1979); none is extinct, and one, *Charcotia actinochilus*, is an indicator species for the Brunhes normal polarity epoch

Nonmarine species account for approximately half of all the diatoms in the Amundsen Sea cores. Most of these species occur in perched deltas in Taylor Valley (Kellogg, Stuiver, et al. 1980), where they were deposited as former glacial lake Washburn receded. (Lake Washburn once filled most of Taylor Valley, including the basins now occupied by lakes Fryxell, Hoare, and Bonney and the spaces in between, to an elevation of about 300 meters.) We also found many of these species living today in melt ponds on the McMurdo Ice Shelf (D. Kellogg, unpublished data, University of Maine at Orono, 1980), where they were also studied by Brady (1979). Our previous analyses of Recent and late Pleistocene Ross Sea sediments occasionally revealed rare specimens of these nonmarine species. However, because they never constituted more than 1 percent of any individual sample, we ascribed their occurrence in Ross Sea sediments to contamination by ice rafting or wind transport. We have no evidence to suggest that they are endemic to the marine environment.

Although our preliminary diatom data from the Amundsen Sea are sparse, they do permit formulation of several hypotheses for further testing. We believe the lower layer (diamicton) is a basal till, on the basis of its sedimentology and overcompaction. The upper layer, therefore, probably represents postglacial deposition in the outer Amundsen Sea. Support for this hypothesis comes from the Brunhes age of *Charcotia actinochilus* and from the dominantly marine nature of the diatom flora in the upper layer. The fact that the upper layer is very thin (2 to 10 centimeters) suggests that Recent sediments were removed by bottom currents, that postglacial deposition was very slow, or that grounded ice was present until recently on the outer continental shelf in the Amundsen Sea. The nature of these soft, fine-grained sediments appears to rule out the possibility of current action. The seaward margins of antarctic continental shelves are usually highly productive, and Recent deposition rates elsewhere in this zone are high (on the order of 10 centimeters per 1,000 years; Kellogg and Truesdale 1979). Thus, slow deposition seems unlikely unless an ice shelf was present, reducing productivity, until quite recently. The third alternative is that grounded ice occupied the Amundsen Sea shelf to the continental shelf margin until perhaps as recently as the last 1,000 years. We are as yet unable to determine whether an ice shelf or grounded ice was responsible for the observed sedimentary distributions. In either case, nonmarine diatoms living in melt ponds on the surface of this ice probably were introduced to the underlying sediment by melt streams flowing down crevasses or off the ice edge.

These tentative hypotheses to explain observed sediment and floral distributions require further verification. If correct, they have considerable significance for the glacial history and dynamics of the west antarctic ice sheet. Further, they appear to support recent glaciologic modeling of the major ice streams entering the Amundsen Sea, which suggests that irreversible downdraw of the center of the west antarctic ice sheet should have occurred unless Pine Island and Thwaites Glaciers were buttressed until quite recently by grounded ice or by an ice shelf in the Amundsen Sea (Hughes 1981; Hughes, Fastook and Denton 1980; Stuiver et al. 1981). We are continuing sedimentologic and microfossil analyses on the Amundsen Sea cores to attempt to answer these fundamental questions.

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Preliminary results from the USARP 1982 marine geologic investigation of the northern Antarctic Peninsula region

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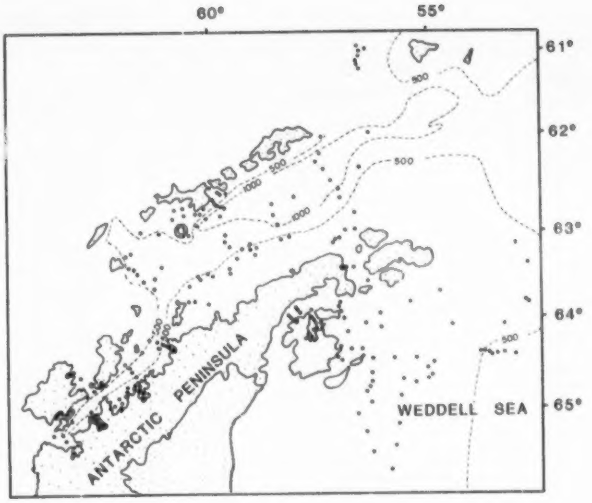
During the 1982 marine geologic expedition of the U.S. Coast Guard icebreaker *Glacier*, 205 geologic sampling stations were occupied in the area of the northern Antarctic Peninsula (figure). Piston cores and bottom samples were acquired from previously unsampled areas of the northwestern Weddell Sea continental shelf and the Bransfield Strait, and more precise bathymetric maps of these areas were constructed. Included in this survey was the sampling and seafloor mapping of 14 fiords in the region (figure). In addition, sediment traps were deployed in the Bransfield Strait and water column geochemical studies were conducted at two stations, one in the Weddell Sea and the other in the Bransfield Strait. Pertinent sample information is listed in the table.

The northern Antarctic Peninsula region was selected for this investigation because it is a unique setting for studying the glacial-climatic history of the continent. Because of their higher latitude position and rather restricted drainage basins, the glaciers of this region undoubtedly are more sensitive to climatic change than are the east antarctic and west antarctic ice sheets. It is hoped that the Quaternary climatic record of the continent is imprinted in the sedimentary record of this region in such a way that it can be clearly interpreted and dated. Our preliminary observation, made during the cruise, leaves us optimistic about achieving these objectives.



Station locations.

Several piston cores were collected from the continental shelf of the northwestern Weddell Sea, adjacent to the Larsen Ice Shelf. Preliminary examination of these cores suggests that they penetrated glacial marine sediments, not basal tills.

Sedimentation within the Bransfield Strait is dominated by siliceous ooze deposition in the deeper parts of the basin and marine current reworking of glacial sediments in shallower areas. Ancient sediments acquired from fiords include siliceous ooze, silts, and diamictons. These sediments are believed to represent variations in climatic conditions ranging from a cold glacial setting (colder than today) when glacial deposition

(Text continues on page 131.)

1982 geologic stations

Station number	Latitude	Longitude	Depth (meters)	Piston core length (cm)	Grab
1	63°57.2′S	56°21.6′W	430	270	✓
2	64°13.8′S	56°24.1′W	190	10	N.T.*
3	64°22.3′S	56°26.7′W	280	82	✓
4	64°31.5′S	56°42.2′W	183	18	✓
5	64°32.1′S	56°47.8′W	211	N.T.	✓
6	64°34.7′S	56°48.0′W	232	N.T.	✓
7	64°42.5′S	56°30.5′W	345	19	✓
8	64°47.1′S	56°47.0′W	420	305	✓
9	64°55.0′S	56°27.0′W	442	272	✓
10	65°07.0′S	56°28.5′W	523	271	✓
11	65°14.6′S	56°14.2′W	525	323	✓
12	65°05.1′S	55°55.5′W	513	374	N.T.
13	64°53.0′S	55°47.0′W	457	82	N.T.
14	64°36.6′S	55°43.9′W	336	268	✓
15	64°30.1′S	55°42.8′W	293	175	✓
16	64°25.0′S	55°23.0′W	347	265	✓

(Table continues on next page.)

1982 geologic stations—Continued

Station number	Latitude	Longitude	Depth (meters)	Piston core length (cm)	Grab
17	64°30.0′S	55°00.7′W	360	234	✓
18	64°19.5′S	55°01.5′W	314	37	N.T.
19	64°15.1′S	55°28.0′W	342	276	✓
20	64°14.1′S	55°54.4′W	381	292	N.T.
21	64°05.5′S	54°14.0′W	415	8	✓
22	64°05.4′S	54°14.2′W	509	214	✓
23	64°06.3′S	54°11.6′W	621	267	N.T.
24	64°06.8′S	54°04.9′W	851	110	✓
25	64°08.0′S	53°56.0′W	1,252	236	✓
26	64°09.5′S	53°50.0′W	1,520	267	✓
27	64°07.3′S	53°46.0′W	1,462	Hydro cast	N.T.
28	63°52.6′S	53°18.7′W	703	210	✓
29	63°38.0′S	52°49.0′W	729	8	✓
30	63°17.0′S	52°50.0′W	448	10	✓
31	63°00.0′S	53°08.0′W	448	10	N.T.
32	62°04.0′S	57°24.0′W	97	10	N.T.
33	62°12.2′S	57°27.8′W	1,934	N.T.	✓
34	62°12.2′S	57°37.4′W	1,979	595	✓
35	62°21.7′S	57°22.0′W	1,484	613	✓
36	62°27.9′S	57°10.3′W	1,072	581	✓
37	62°33.2′S	56°59.3′W	728	48	N.T.
38	62°35.4′S	56°54.0′W	366	58	✓
39	62°45.8′S	56°44.1′W	190	N.T.	✓
40	62°57.7′S	56°48.4′W	91	N.T.	✓
41	63°06.5′S	57°12.7′W	521	16	N.T.
42	63°04.3′S	57°06.3′W	336	8	N.T.
43	63°01.7′S	57°03.3′W	56	40	✓
44	63°01.5′S	57°31.1′W	116	N.T.	✓
45	63°02.9′S	58°11.8′W	149	N.T.	✓
46	63°03.9′S	58°20.9′W	765	289	N.T.
47	62°55.3′S	58°23.7′W	723	297	✓
48	62°48.2′S	58°28.1′W	840	286	✓
49	62°42.5′S	58°29.7′W	1,567	62	✓
50	62°37.1′S	58°28.0′W	1,661	574	N.T.
51	63°43.4′S	60°02.9′W	560	287	✓
52	63°40.9′S	60°19.6′W	224	8	✓
53	63°36.6′S	60°28.0′W	364	N.T.	✓
54	63°29.1′S	60°23.4′W	588	190	✓
55	63°24.0′S	60°15.0′W	719	99	✓
56	63°25.0′S	60°12.5′W	425	15	✓
57	63°24.8′S	60°09.5′W	230	N.T.	✓
58	63°25.5′S	59°56 ′W	140	N.T.	✓
59	63°23.4′S	59°36.8′W	125	N.T.	✓
60	63°23.4′S	59°34.2′W	673	10	✓
61	63°17.0′S	59°20.2′W	728	280	✓
62	63°14.8′S	58°58.9′W	122	N.T.	✓
63	63°11.6′S	58°57.9′W	145	N.T.	✓
64	63°09.1′S	59°07.4′W	280	50	✓
65	63°09.6′S	59°13.2′W	560	56	N.T.
66[b]	63°09.0′S	59°18.2′W	793	600	N.T.
67	63°08.7′S	59°43.4′W	466	10	N.T.
68	63°06.6′S	59°41.9′W	405	264	N.T.
69	62°59.9′S	59°38.1′W	916	275	✓
70	62°48.3′S	59°44.9′W	486	72	✓
71	62°38.4′S	59°32.0′W	1,350	305	✓
72	62°37.2′S	59°34.8′W	905	25	N.T.
73	62°36.5′S	59°40.3′W	551	285	✓
74	62°35.8′S	59°41.8′W	521	283	✓
75	62°31.0′S	59°57.0′W	200	282	✓

1982 geologic stations—Continued

Station number	Latitude	Longitude	Depth (meters)	Piston core length (cm)	Grab
76	62°39.8′S	59°54.6′W	93	N.T.	✓
77	62°40.9′S	59°54.1′W	186	N.T.	✓
78	62°44.3′S	59°52.9′W	278	N.T.	✓
79	62°41.2′S	59°51.3′W	448	N.T.	✓
80	62°40.9′S	59°50.1′W	522	8	N.T.
81	62°47.8′S	60°19.8′W	106	N.T.	✓
82	62°48.9′S	60°16.2′W	205	N.T.	✓
83	62°46.2′S	60°16.0′W	308	N.T.	✓
84	62°49.5′S	60°11.4′W	840	253	✓
85	62°48.5′S	60°42.4′W	200	77	✓
86	62°42.5′S	60°39.9′W	150	N.T.	✓
87	62°42.1′S	60°33.0′W	265	288	✓
88	62°49.5′S	60°26.7′W	455	98	✓
89	62°57.3′S	60°13.0′W	990	132	✓
90	63°02.8′S	60°26.3′W	538	N.T.	✓
91[c]	63°06.9′S	61°09.1′W	766	500	N.T.
92	63°05.4′S	61°34.4′W	635	84	N.T.
93	64°04.1′S	61°19.6′W	690	295	✓
94	64°05.1′S	61°11.0′W	273	N.T.	N.T.
95	64°06.5′S	61°00.7′W	215	N.T.	✓
96	64°07.7′S	60°58.0′W	304	N.T.	✓
97	64°08.8′S	60°54.5′W	334	272	✓
98	64°08.2′S	60°56.0′W	284	282	✓
99	64°07.0′S	60°59.5′W	289	44	N.T.
100	64°09.5′S	61°16.8′W	526	294	✓
101	64°11.8′S	61°33.0′W	161	N.T.	✓
102	64°18.6′S	61°52.7′W	540	279	✓
103	64°21.2′S	61°48.6′W	275	N.T.	✓
104	64°21.8′S	61°45.2′W	482	N.T.	N.T.
105	64°25.0′S	61°45.5′W	170	17	✓
106	64°30.7′S	61°40.2′W	482	N.T.	✓
107	64°33.7′S	61°37.0′W	298	N.T.	✓
108	64°33.0′S	61°40.0′W	341	276	✓
109	64°36.2′S	61°34.0′W	439	286	✓
110	64°36.2′S	62°30.5′W	157	N.T.	✓
111	64°38.1′S	61°37.5′W	344	578	✓
112	64°36.5′S	61°38.0′W	600	N.T.	✓
113	64°36.2′S	61°39.6′W	144	372	✓
114	64°34.8′S	61°38.3′W	429	N.T.	✓
115	64°31.8′S	61°36.7′W	299	N.T.	✓
116	64°33.0′S	61°40.9′W	162	N.T.	✓
117	64°33.2′S	61°57.7′W	340	250	✓
118	64°38.2′S	62°01.5′W	243	N.T.	✓
119	64°33.8′S	62°58.0′W	345	71	N.T.
120	64°30.5′S	62°29.7′W	299	10	N.T.
121	64°29.3′S	62°30.7′W	112	41	✓
122	64°28.0′S	62°31.5′W	130	16	N.T.
123	64°28.4′S	62°31.8′W	233	307	✓
124	64°42.2′S	62°13.5′W	396	133	✓
125	64°41.5′S	62°03.9′W	314	260	✓
126	64°42.6′S	62°03.4′W	246	31	✓
127	64°39.5′S	62°07.4′W	443	264	✓
128	64°26.3′S	63°19.6′W	317	20	N.T.
129	64°25.7′S	63°18.1′W	498	20	N.T.
130	64°24.5′S	63°15.0′W	631	242	✓
131	64°23.5′S	63°14.8′W	345	565	✓
132	64°22.7′S	63°11.4′W	560	595	N.T.

(Table continues on next page.)

1982 geologic stations—Continued

Station number	Latitude	Longitude	Depth (meters)	Piston core length (cm)	Grab
133	64°26.1'S	62°57.2'W	644	592	N.T.
134	64°34.5'S	62°39.0'W	793	564	✓
135[d]	64°38.9'S	62°53.4'W	532	49	N.T.
136	64°45.4'S	62°45.5'W	452	277	N.T.
137	64°47.7'S	62°43.0'W	368	269	N.T.
138	64°49.2'S	62°37.2'W	112	N.T.	✓
139	64°51.4'S	62°39.0'W	85	N.T.	✓
140	64°49.6'S	62°37.8'W	392	280	✓
141	64°52.0'S	62°32.7'W	306	113	✓
142	64°53.1'S	62°26.4'W	541	226	✓
143	64°52.4'S	62°30.1'W	411	276	✓
144	64°54.0'S	62°37.3'W	261	80	✓
145	64°54.9'S	62°35.5'W	261	N.T.	✓
146	64°53.5'S	62°37.6'W	158	N.T.	✓
147	64°53.2'S	62°36.1'W	317	167	✓
148	64°51.0'S	62°37.5'W	345	120	✓
149	64°48.5'S	62°42.5'W	332	252	✓
150	64°51.2'S	63°10.0'W	336	41	✓
151	64°58.0'S	63°20.1'W	360	287	N.T.
152	65°05.3'S	63°10.1'W	485	212	✓
153	65°08.0'S	63°11.5'W	351	46	✓
154	65°05.3'S	63°10.0'W	689	232	✓
155	65°01.2'S	63°15.6'W	437	281	✓
156	64°56.4'S	63°37.0'W	608	273	N.T.
157	63°35.0'S	64°44.5'W	224	208	N.T.
158	64°44.8'S	61°33.0'W	136	N.T.	✓
159	64°43.8'S	63°15.3'W	374	8	✓
160	64°46.0'S	63°19.5'W	374	62	✓
161	64°44.5'S	63°29.0'W	187	157	✓
162	64°47.0'S	63°31.5'W	317	6	✓
163	63°23.5'S	57°01 'W	317	207	✓
164	63°23.2'S	56°59.8'W	299	160	N.T.
165	63°22.9'S	56°59.0'W	243	8	N.T.
166[e]	63°28.2'S	56°35.9'W	952	554	N.T.
167	63°52.5'S	56°36.6'W	448	285	✓
168	63°52.1'S	57°00.0'W	429	266	✓
169	64°03.2'S	56°34.5'W	228	36	✓
170	64°00.0'S	56°50.0'W	177	25	✓
171	64°15.0'S	57°09.5'W	224	281	✓
172	64°14.5'S	57°13.2'W	131	83	N.T.
173	64°08.0'S	57°04.4'W	233	N.T.	✓
174	64°10.0'S	56°48.5'W	288	295	✓
175	63°50.2'S	58°14.6'W	560	5	✓
176	63°53.6'S	58°06.5'W	168	145	✓
177	63°52.4'S	58°10.5'W	211	N.T.	N.T.
178	63°48.3'S	58°01.0'W	689	44	✓
179	63°48.0'S	58°05.1'W	747	8	✓
180	63°50.0'S	57°58.5'W	65	6	✓
181	63°48.4'S	58°04.5'W	769	206	N.T.
182	63°51.3'S	57°42.8'W	405	259	✓
183	63°59.4'S	57°43.5'W	299	290	✓
184	64°02.7'S	57°45.5'W	383	304	N.T.
185	64°04.5'S	57°45.0'W	383	268	N.T.
186	64°05.0'S	57°49.0'W	299	236	✓
187	64°02.0'S	57°47.0'W	265	276	✓
188	63°58.8'S	57°50.3'W	198	22	✓
189	63°57.2'S	57°39.7'W	340	74	N.T.
190	65°55.9'S	57°38.6'W	41	N.T.	✓
191	63°55.3'S	57°34.1'W	95	21	✓
192[f]	63°54.5'S	57°41.6'W	350	533	N.T.

1982 geologic stations—Continued

Station number	Latitude	Longitude	Depth (meters)	Piston core length (cm)	Grab
193	63°45.5′S	57°43.0′W	786	110	N.T.
194	63°48.0′S	57°44.6′W	282	N.T.	✓
195	63°47.2′S	57°23.5′W	234	N.T.	✓
196	63°45.5′S	57°20.0′W	696	122	✓
197	63°43.0′S	57°13.6′W	750	235	✓
198	62°21.3′S	56°24.3′W	629	96	✓
199	61°57.5′S	56°18.6′W	1,980	129	N.T.
200	61°17.2′S	56°32.0′W	560	10	N.T.
201	61°15.7′S	56°33.2′W	898	15	N.T.
202	61°13.4′S	56°36.0′W	452	80	N.T.
203[g]	61°11.2′S	56°37.5′W	1,102	8	N.T.
204[h]	61°08.3′S	56°38.1′W	1,367	101	N.T.
205	61°07.1′S	56°37.0′W	1,639	10	N.T.

[a] N.T. = not taken.

[b] Trigger core, 20 centimeters.

[c] Trigger core, 50 centimeters.

[d] Trigger core, 9 centimeters.

[e] Trigger core, 8 centimeters.

[f] Trigger core, 30 centimeters.

[g] Trigger core, 4 centimeters.

[h] Trigger core, 22 centimeters.

(Continued from page 127.)

prevailed to much warmer episodes when meltwater input of silts occurred. Currently, siliceous ooze is filling these fiords; ice-rafting and meltwater sediment input are insignificant.

Ongoing sedimentologic investigations of piston cores from antarctic fiords are aimed at investigating sedimentation within these unique glacial marine environments and at developing a high-resolution, Quaternary glacial-climatic record using rapidly sedimented deposits.

This work was supported by National Science Foundation grant DPP 81-16623. Participants in the marine geologic cruise included myself, Chris Brake, Pam Fisco, Jill Singer, and Robyn Wright of Rice University, Paul Ciesielski of the University of Georgia, and Peter Webb of Ohio State University. We are all indebted to the crew of the U.S. Coast Guard icebreaker *Glacier* and the attached helicopter division for their support during the cruise.

Summary of sediment descriptions of ARA *Islas Orcadas* cruise 15 piston cores

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Cruise 15-78 of ARA *Islas Orcadas* (John L. LaBrecque, chief scientist) collected a total of 51 liner-encased piston cores (figure 1). This article presents a summary of the descriptions of 46 of these cores, along six traverses, in the form of graphic lithologic logs (figures 2 and 3). Limitations of space make it necessary to omit the graphic logs of five cores (20, 27, 47, 48, 50), the lithologies of which are similar to those of other cores in their vicinities.

These lithologic logs represent very generalized descriptions of the cores; detailed sediment descriptions can be found in Kaharoeddin and others (1980). Basal sediment ages referred to in this article are based on the work of Ciesielski and Jones (1979).

Cores 64, 63, and 62, in the Scotia Sea, consist generally of Quaternary diatomaceous muds. The two northernmost cores (64 and 63), despite being close to one another, obviously represent different sedimentary regimes. Evidence for this is provided by the abundance of pebbles and sedimentary clasts found in core 63. Farther south, core 61 is composed of early Pliocene mud and diatomaceous mud. Approaching the escarpment north of the South Orkney Islands one finds Eocene to Oligocene pelagic clays (core 59).

West of the South Sandwich Islands the predominant sediment is Quaternary volcanic ash (core 2), overlain by interbedded diatomaceous and muddy diatomaceous oozes containing

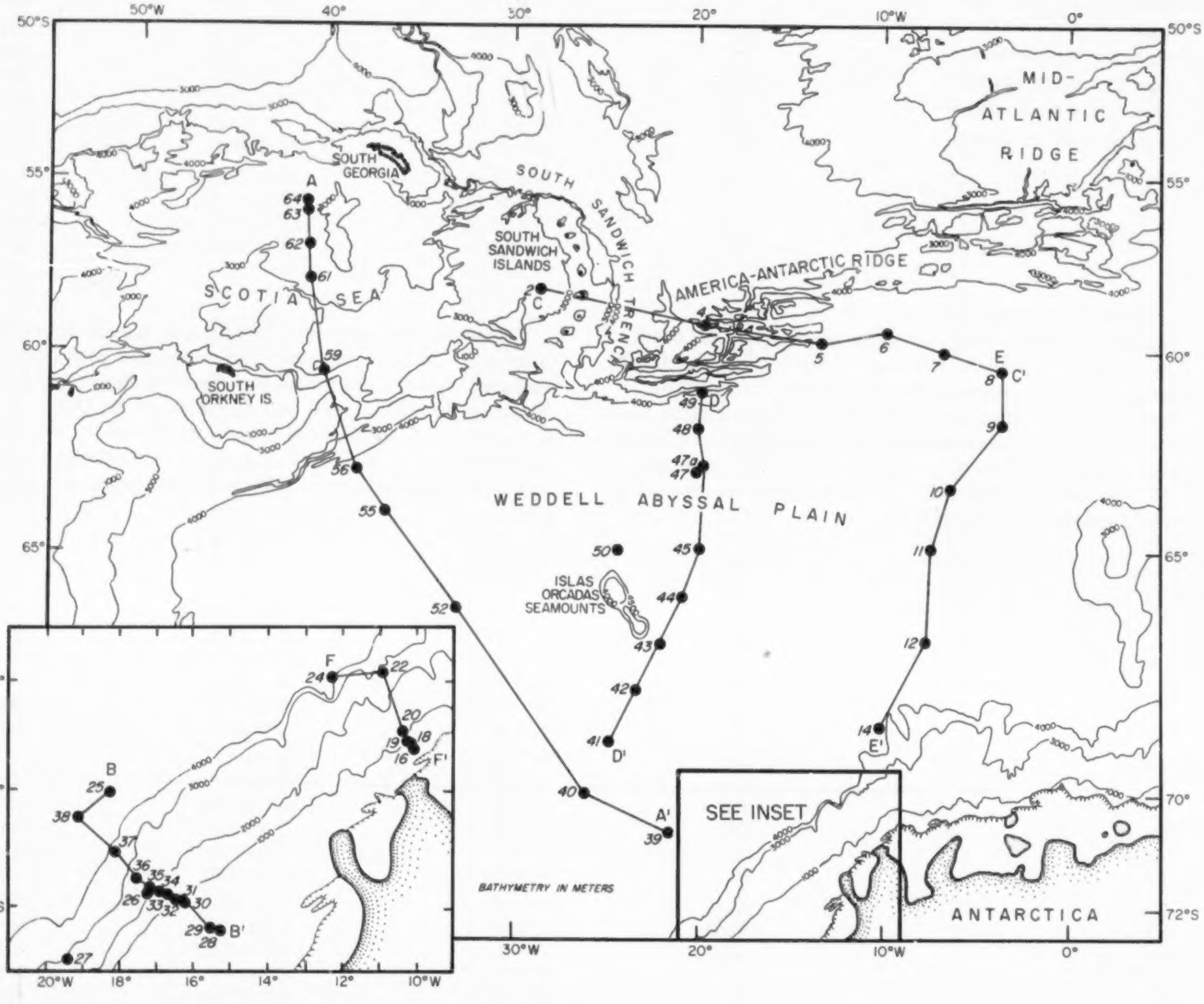
50°W
40°
30°
20°
10°W
0°
50°S
55°
60°
65°
70°
72°S
MID-ATLANTIC RIDGE
SOUTH GEORGIA
SOUTH SANDWICH ISLANDS
SOUTH SANDWICH TRENCH
SCOTIA SEA
AMERICA-ANTARCTIC RIDGE
SOUTH ORKNEY IS.
WEDDELL ABYSSAL PLAIN
ISLAS ORCADAS SEAMOUNTS
ANTARCTICA
SEE INSET
BATHYMETRY IN METERS
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
3000
4000
30°W
20°
10°W
0°
20°W
18°
16°
14°
12°
10°W
70°
71°
72°S

Figure 1. Locations of piston cores retrieved aboard ARA *Islas Orcadas* cruise 15-78.

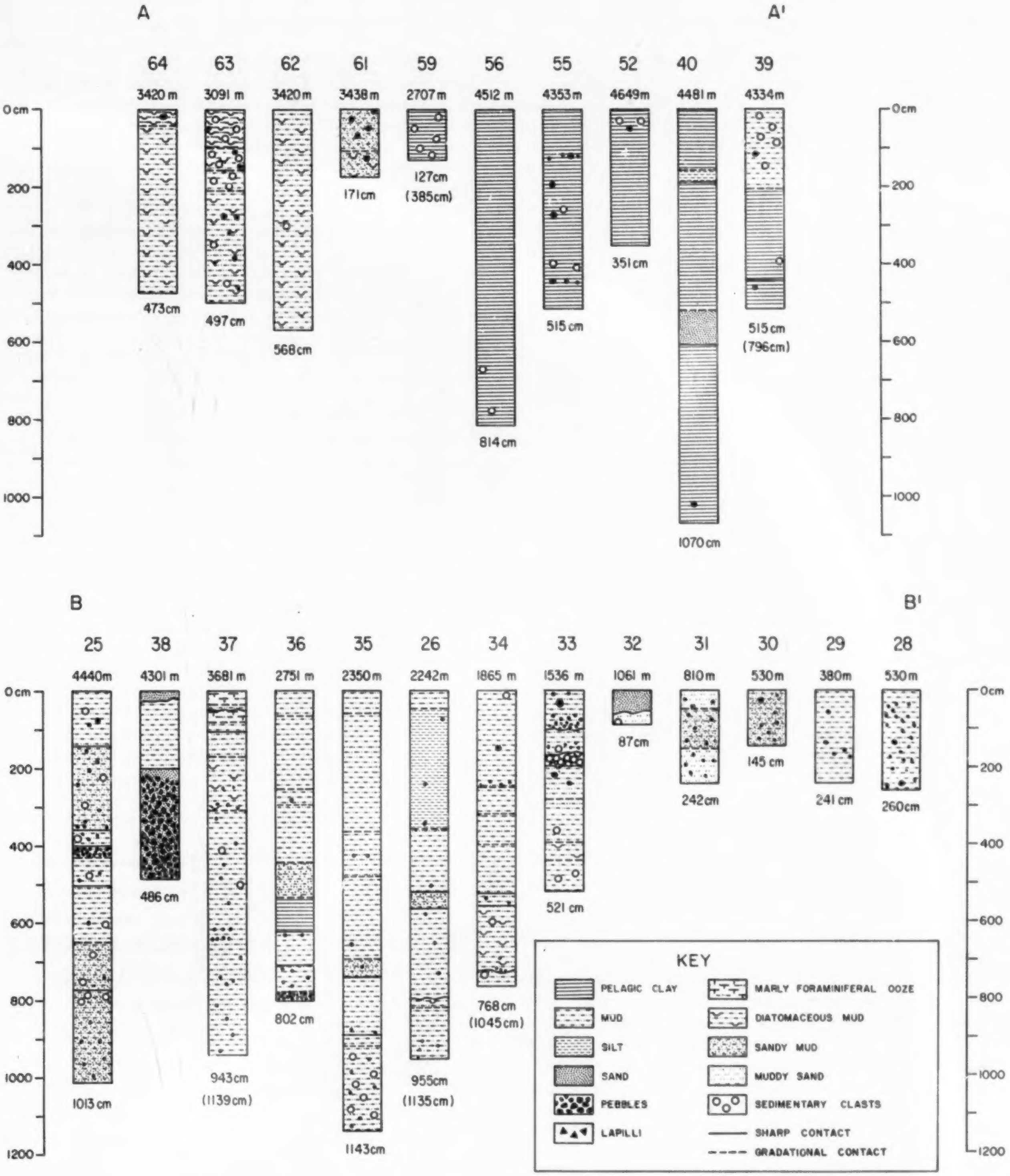
A
A'
64
3420 m
473cm
63
3091 m
497cm
62
3420m
568cm
61
3438m
171cm
59
2707m
127cm
(385cm)
56
4512 m
814cm
55
4353m
515cm
52
4649m
351cm
40
4481 m
1070cm
39
4334m
515cm
(796cm)
0cm
200
400
600
800
1000
B
B'
25
4440m
1013cm
38
4301 m
486cm
37
3681 m
943cm
(1139cm)
36
2751 m
802cm
35
2350m
1143cm
26
2242m
955cm
(1135cm)
34
1865 m
768cm
(1045cm)
33
1536 m
521 cm
32
1061 m
87cm
31
810m
242cm
30
530m
145 cm
29
380m
241 cm
28
530m
260cm
1200
KEY
PELAGIC CLAY
MUD
SILT
SAND
PEBBLES
LAPILLI
MARLY FORAMINIFERAL OOZE
DIATOMACEOUS MUD
SANDY MUD
MUDDY SAND
SEDIMENTARY CLASTS
SHARP CONTACT
GRADATIONAL CONTACT

Figure 2. Simplified lithologic logs along traverses A–A′ and B–B′ (see figure 1). Numbers above log are core number and water depth; number at base of log is core length; number at base in parentheses is actual core length, including flow-in portion (not shown).

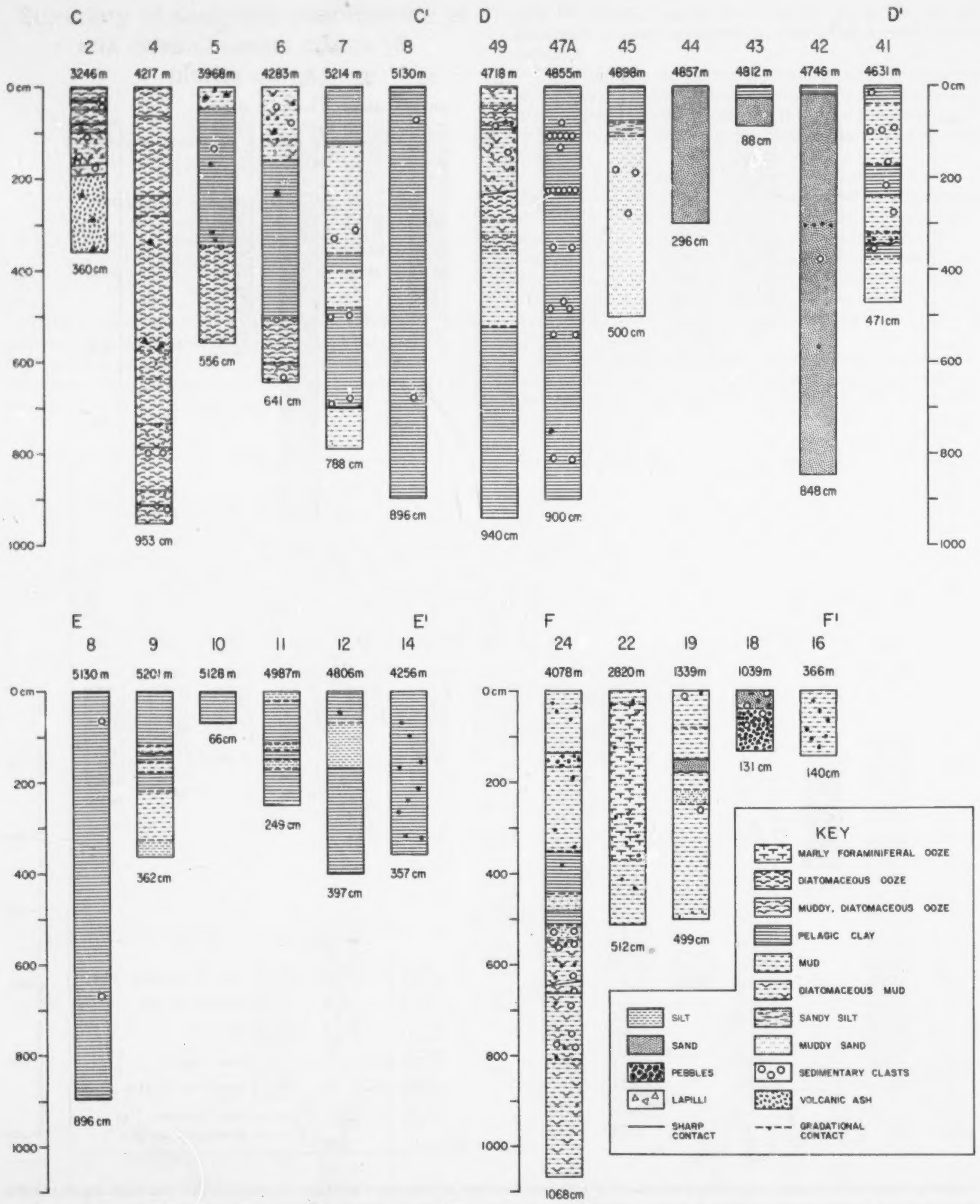
C
C'
D
D'
2
4
5
6
7
8
49
47A
45
44
43
42
41
3246m
4217 m
3968m
4283m
5214 m
5130m
4718 m
4855m
4898m
4857m
4812 m
4746 m
4631 m
0cm
200
400
600
800
1000
360cm
953 cm
556cm
641 cm
788 cm
896cm
940cm
900cm
500 cm
296cm
88cm
848cm
471cm
E
E'
F
F'
8
9
10
11
12
14
24
22
19
18
16
5130m
5201 m
5128 m
4987m
4806m
4256m
4078m
2820m
1339m
1039m
366m
896 cm
362cm
66cm
249cm
397cm
357cm
1068cm
512cm
499cm
131 cm
140cm
KEY
MARLY FORAMINIFERAL OOZE
DIATOMACEOUS OOZE
MUDDY, DIATOMACEOUS OOZE
PELAGIC CLAY
MUD
DIATOMACEOUS MUD
SANDY SILT
MUDDY SAND
SEDIMENTARY CLASTS
VOLCANIC ASH
SILT
SAND
PEBBLES
LAPILLI
SHARP CONTACT
GRADATIONAL CONTACT

Figure 3. Simplified lithologic logs along traverses C–C′, D–D′, E–E′, and F–F′. Numbers above log are core number and water depth; number at base of log is core length.

sedimentary clasts. Sediments across the America-Antarctic Ridge (core 4) are composed of Quaternary diatomaceous ooze occasionally rich in volcanic ash.

Farther to the east, and approaching the Weddell basin, sediments are pelagic clays and muds (cores 5 through 8). Only core 8 has a Quaternary basal sediment, while basal sediments of cores 5 through 7 predate middle Pliocene. This is similar to the situation farther east in sediments south of the Atlantic-Indian Ridge, where buried disconformities also have been documented (Ledbetter and Ciesielski 1981). Other cores on the northern part of the Weddell basin (cores 56 and 49) are composed of Quaternary pelagic clay overlain by ash-bearing diatomaceous ooze (core 49).

Sediments in the Weddell abyssal plain proper are mostly barren of microfossils; thus, basal ages of the cores in this area cannot be determined. Sediments in the western part of the abyssal plain (traverse A–A′; cores 55, 52, and 40) generally are composed of pelagic clay bearing minor amounts of sand and silt (core 40). Similarly, pelagic clay is found on the northern part of traverse D–D′ (core 47a), as well as in cores 48 and 47 (Kaharoeddin et al. 1980). However, in the vicinity of the Islas Orcadas Seamounts (traverse D–D′; cores 45 through 42) the primary sediment is sand, with minor amounts of clay, an occurrence that probably can be attributed to local factors. Core 50, which is composed of interbedded clay and sand (Kaharoeddin et al. 1980), shows the effect of both general and local sedimentation patterns. In the eastern part of the abyssal plain along traverse E–E′ (cores 9 through 12) the pelagic clay is interbedded with silt and mud.

Cores on the continental margin can be divided into two groups: those on the continental rise and those on the continental terrace. The continental rise cores include cores 25 through 33 (traverse B–B′) and cores 24 and 22 (traverse F–F′). In general, these cores consist of mud and interbedded sandy mud, characterized by an abundance of sedimentary clasts and pebbles and also showing evidence of unconformities separating the lower Miocene and younger sediments. Core 22 is an exception to this pattern, as it consists primarily of marly foraminiferal ooze, a lithology that is indicative of a local high productivity coupled with a favorable carbonate compensation depth. Core 24 penetrates lower Oligocene sediments and is composed of diatomaceous mud. The unconformities along the continental margin have been documented by Ledbetter and Ciesielski (1981) for sediments from cruise 12-77 of ARA *Islas Orcadas*. Cores 39 and 14, which were recovered from the lower continental rise, are composed of clay and mud having an abundance of sedimentary clasts and pebbles. Their composition indicates that these two cores are the product of both abyssal plain and continental margin sedimentary processes. They contain several unconformities, and their basal ages are early Miocene.

Continental terrace cores, which include cores 32 through 28 (traverse B–B′) and cores 20 through 16 (traverse F–F′), consist mostly of sand, mud, and a mixture of the two, except core 18, which is composed largely of pebbles. Although basal sediments of these cores are mostly barren, they are all believed to be Quaternary in age; this assumption is based on the basal ages of cores 32 and 28.

We wish to acknowledge Dennis Cassidy for his help in several phases of this work, including photography of the figures. Rosemarie Raymond drafted the figures. This work has been supported by National Science Foundation contract C-1059.

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Ledbetter, M. T., and Ciesielski, P. F. 1981. Bottom-current erosion in the South Atlantic sector of the southern ocean. *Antarctic Journal of the U.S.*, 16(5), 110–112.

Summary of sediment descriptions of ARA *Islas Orcadas* cruise 16 piston cores

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The primary goals of the coring program aboard cruise 16-78 of ARA *Islas Orcadas* (Sherwood W. Wise, Jr., chief scientist) were to survey older (pre-Pliocene) sediments of the Maurice Ewing Bank, the Georgia Basin, and the Islas Orcadas Rise and to trace the flow of antarctic deep water in the southwest Atlantic Ocean between the Mid-Atlantic Ridge and the America-Antarctic Ridge (Wise et al. 1978). A total of 69 piston cores were recovered, of which 68 were received at the Antarctic Research Facility (figure 1).

This article presents a summary of the descriptions of these cores, based on the more detailed sediment descriptions prepared by Kaharoeddin and associates (1982). Although the locations of all cores are shown in figure 1, limitations of space make it necessary to omit the lithologic logs of 20 cores from the graphic summary presented in figures 2 and 3. (The omitted cores are 23, 24, 27, 34, 37, 41, 44, 50, 51, 57, 65, 67, 70, 83, 104, 105, 106, 111, 114, and 117.) Discussion of basal ages of the cores is based on the work of Jones and associates (1979).

Of the 32 piston cores taken on the Maurice Ewing Bank, only 18 recovered undisturbed (by flow-in) sediments greater than 100 centimeters in length. All 32 of these cores are relatively

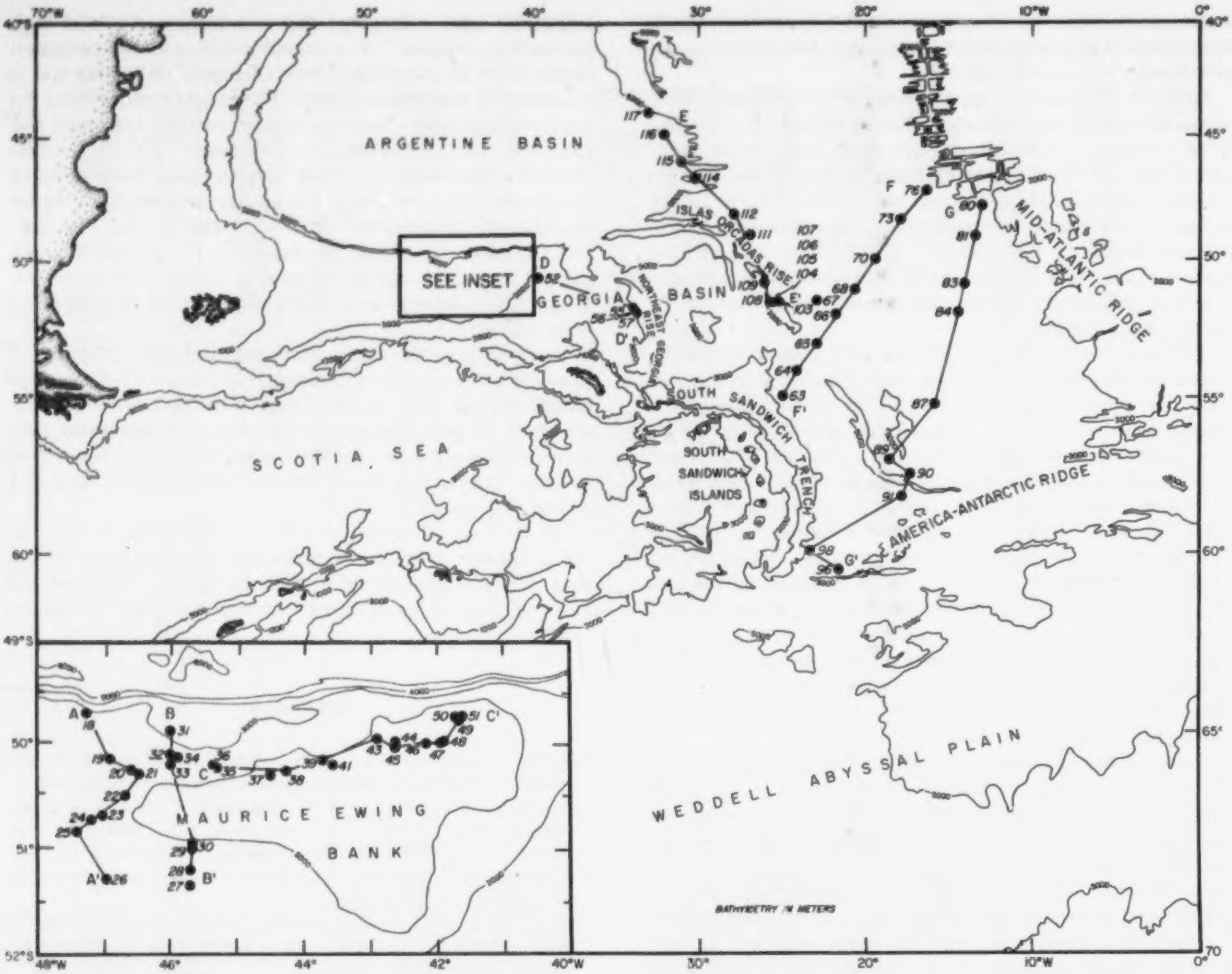
70°W
60°
50°
40°
30°
20°
10°W
0°
40°S
45°
50°
55°
60°
65°
70
ARGENTINE BASIN
SEE INSET
SCOTIA SEA
GEORGIA BASIN
NORTHEAST GEORGIA RISE
ISLAS ORCADAS RISE
SOUTH SANDWICH TRENCH
SOUTH SANDWICH ISLANDS
MID-ATLANTIC RIDGE
AMERICA-ANTARCTIC RIDGE
WEDDELL ABYSSAL PLAIN
MAURICE EWING BANK
BATHYMETRY IN METERS
D
D'
E
E'
F
F'
G
G'
A
A'
B
B'
C
C'
49°S
50°
51°
52°S
48°W
46°
44°
42°
40°W

Figure 1. Locations of piston cores recovered aboard cruise 16-78 of ARA *Islas Orcadas*.

short, with their undisturbed portions ranging from 20 to 520 centimeters. Three of the cores (23, 24, 51) for which lithologic logs are not shown in figure 2 penetrated only Quaternary sediments consisting of foraminiferal sand or sandy foraminiferal ooze. Core 27, also not shown, is similar to core 29; it consists of pelagic clay containing some zeolites. (These cores are very similar to *Islas Orcadas* piston core 0775-50, which has been dated by Ciesielski and Wise, 1977, as Eocene in age.) Other cores in this area not shown in figure 2 (cores 34, 37, 41, 44, and 50) are similar in lithology to one or more of their companion cores whose logs are shown.

Most of the pre-Pliocene sediments on the Maurice Ewing Bank range in age from late Miocene to late Paleocene and consist of nannofossil ooze occasionally containing common to abundant diatoms and/or radiolarians. Exceptions to this are core 20 (diatomaceous mud), core 25 (glauconitic, sandy diatomaceous ooze), core 26 (muddy diatomaceous ooze), core 28 (diatomaceous sand), and core 19 (intermixed diatomaceous ooze and glauconitic, sandy siliceous ooze). Numerous unconformities can be seen in these cores. A detailed discussion of the unconformities in Neogene sediments in this area can be found in Ciesielski and others (1982).

On the western flank of the northeast Georgia Rise, two cores (55 and 56) penetrated lower Pliocene sediments; however, they consist of differing lithologies. When combined, these two cores provide an excellent Pliocene record (Wise et al. 1978). Evidence of unconformities can be seen in the top parts of these cores. One core not shown in figure 2, core 57, is composed primarily of Quaternary foraminiferal diatomaceous ooze overlain by a sandy or muddy diatomaceous ooze.

Cores 103 through 109 were taken on the Islas Orcadas Rise (cores 104–106 are not shown in figure 3). In general, the Islas Orcadas Rise cores are short, but they penetrated pre-Quaternary sediments. In core 104, only the top 37 centimeters is undisturbed by flow-in, although its total length is 662 centimeters. Nevertheless, this core is valuable for stratigraphic work, because the interval between 36 and 37 centimeters consists of a lower Oligocene nannofossil ooze overlain by a sandy, muddy diatomaceous ooze. Cores 105 (220 centimeters) and 106 (47 centimeters) are lithologically similar to the upper part of core

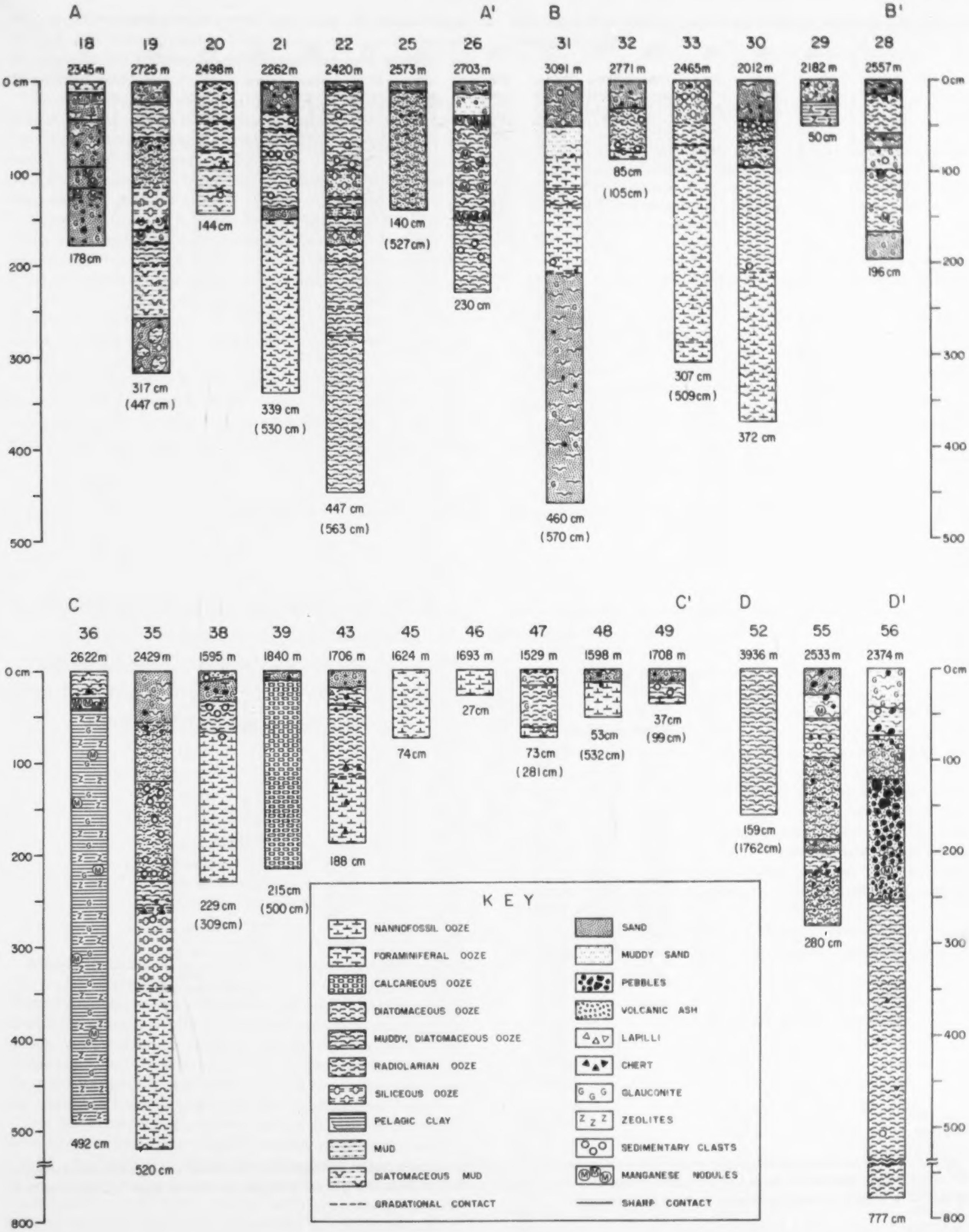
A
A'
B
B'
18 2345m 178cm
19 2725 m 317 cm (447 cm)
20 2498m 144cm
21 2262m 339 cm (530 cm)
22 2420m 447 cm (563 cm)
25 2573m 140 cm (527cm)
26 2703m 230 cm
31 3091 m 460 cm (570 cm)
32 2771m 85cm (105cm)
33 2465m 307 cm (509cm)
30 2012m 372 cm
29 2182m 50cm
28 2557m 196cm
0 cm
100
200
300
400
500
C
C'
D
D'
36 2622m 492 cm
35 2429m 520 cm
38 1595 m 229 cm (309cm)
39 1840 m 215cm (500 cm)
43 1706 m 188 cm
45 1624 m 74cm
46 1693 m 27cm
47 1529 m 73cm (281cm)
48 1598 m 53cm (532cm)
49 1708 m 37cm (99cm)
52 3936 m 159cm (1762cm)
55 2533m 280 cm
56 2374m 777 cm
800
KEY
NANNOFOSSIL OOZE
FORAMINIFERAL OOZE
CALCAREOUS OOZE
DIATOMACEOUS OOZE
MUDDY, DIATOMACEOUS OOZE
RADIOLARIAN OOZE
SILICEOUS OOZE
PELAGIC CLAY
MUD
DIATOMACEOUS MUD
GRADATIONAL CONTACT
SAND
MUDDY SAND
PEBBLES
VOLCANIC ASH
LAPILLI
CHERT
GLAUCONITE
ZEOLITES
SEDIMENTARY CLASTS
MANGANESE NODULES
SHARP CONTACT

Figure 2. Simplified lithologic logs of cores from the Maurice Ewing Bank and the Georgia Basin. Numbers above log are core number and water depth; number at base of log is core length; number at base in parentheses is actual core length, including flow-in portion (not shown).

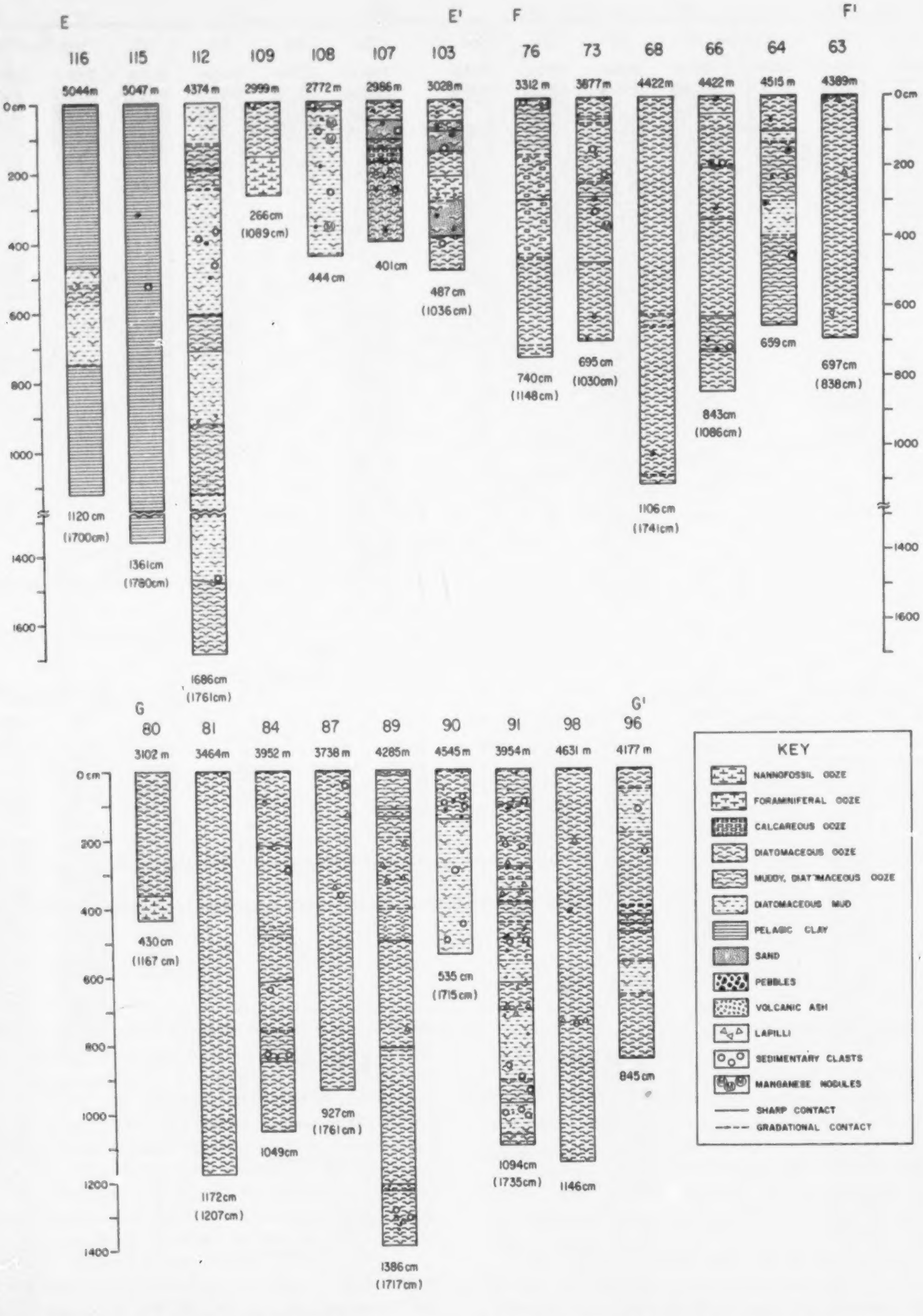
E
E'
F
F'
116
5044m
1120 cm
(1700cm)
115
5047 m
1361cm
(1780cm)
112
4374 m
1686cm
(1761cm)
109
2999m
266cm
(1089cm)
108
2772m
444cm
107
2986m
401cm
103
3028m
487cm
(1036cm)
76
3312 m
740cm
(1148cm)
73
3877m
695cm
(1030cm)
68
4422m
1106cm
(1741cm)
66
4422m
843cm
(1086cm)
64
4515 m
659cm
63
4389m
697cm
(838cm)
0cm
200
400
600
800
1000
1400
1600
G
G'
80
3102 m
430cm
(1167 cm)
81
3464m
1172cm
(1207cm)
84
3952 m
1049cm
87
3738 m
927cm
(1761cm)
89
4285m
1386cm
(1717cm)
90
4545m
535cm
(1715cm)
91
3954m
1094cm
(1735cm)
98
4631 m
1146cm
96
4177 m
845cm
0cm
200
400
600
800
1000
1200
1400
KEY
NANNOFOSSIL OOZE
FORAMINIFERAL OOZE
CALCAREOUS OOZE
DIATOMACEOUS OOZE
MUDDY, DIATOMACEOUS OOZE
DIATOMACEOUS MUD
PELAGIC CLAY
SAND
PEBBLES
VOLCANIC ASH
LAPILLI
SEDIMENTARY CLASTS
MANGANESE NODULES
SHARP CONTACT
GRADATIONAL CONTACT

Figure 3. Simplified lithologic logs of cores in the southwestern sector of the Atlantic Ocean, between the Mid-Atlantic Ridge and the America-Antarctic Ridge. Numbers above log are core number and water depth; number at base of log is core length; number at base in parentheses is actual core length, including flow-in portion (not shown).

103, permitting stratigraphic correlation. Core 109 contains nannofossil ooze of middle to late Miocene age and is unconformably overlain by Quaternary diatomaceous and muddy diatomaceous oozes.

The remaining cores shown in figure 3 are Quaternary in age. Predictable changes in lithology are found in the progression from north to south along traverses E–E′, F–F′, and G–G′. In the deeper part of the Argentine Basin, the sediment consists of pelagic clay (cores 117, 116, and 115). Farther south are primarily diatomaceous ooze and muddy diatomaceous ooze (cores 114, 112, and 111). Less deep, and in the vicinity of the Mid-Atlantic Ridge, are to be found a calcareous diatomaceous ooze (core 76) and a unit of nannofossil ooze (core 80). Although the rest of the cores are primarily diatomaceous ooze, local variations do occur. For example, the sediments of cores 89, 90, and 91, near the America-Antarctic Ridge, contain volcanic ash, lapilli, pebbles, and sedimentary clasts. Unconformities can be observed in several cores.

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Biostratigraphic correlations and regional erosion shown by the radiolarian *Cycladophora davisiana* and the diatoms *Eucampia balaustium* and *Hemidiscus karstenii*

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To conduct sedimentological studies of upper Brunhes southern ocean sediments, it is necessary to use high-resolution biostratigraphic schemes. Three biostratigraphically useful species for the interval 195,000 years before present to recent are the radiolarian *Cycladophora davisiana* and the diatoms *Eucampia balaustium* and *Hemidiscus karstenii*. This article describes their utility in biostratigraphic work with USNS *Eltanin* piston cores from the southeast Indian Ocean (for core locations, see table).

The last-abundant-appearance datum (LAAD) of *Hemidiscus karstenii* has been dated at 195,000 years before present (Burckle, Clarke, and Shackleton 1978). This datum is of marginal utility in the present study, however. Although the datum was well established in cores E49-3, E49-24 (although somewhat stratigraphically high), and E50-9, in cores E50-10, E50-16, and E49-16, the maximum abundance of *Hemidiscus karstenii* is less than 4 percent. In these situations, extreme care must be exercised in interpretation, because faulty slide preparation, erroneous counting, and so forth may result in a "LAAD" being indicated when in fact one is not present. In cores E50-6 and E50-12, no LAAD of *Hemidiscus karstenii* could be detected.

A stratigraphy based on the relative abundances of the radiolarian *Cycladophora davisiana*, one that can be correlated with the oxygen isotope stratigraphy for the last 150,000 years, was proposed by Hays and associates (1976). Their stratigraphy was extended to 500,000 years before present by Williams and Keany (1978). These and other studies (Morley and Hays 1979; Weaver 1979) show low abundances of this radiolarian in recent sediments, followed by an acme estimated to be at 18,000 years before present (Hays et al. 1976). From this acme (interval b), abundances of *C. davisiana* generally decrease in older sediments to interval e_3, estimated to be at 125,000 years before present (Hays et al. 1976).

In the present study, the *C. davisiana* stratigraphy is well developed in four cores—E49-3, E49-24, E50-9, and E49-16 (figure

Piston core locations

Piston core number	Latitude (S)	Longitude (E)
E49-3	45°06.4′	109°54.9′
E49-16	50°26.0′	90°10.6′
E49-24	47°59.3′	95°02.2′
E50-6	48°01.6′	105°14.6′
E50-9	52°01.3′	105°00.6′
E50-10	53°58.7′	104°56.2′
E50-12	57°57.2′	105°01.0′
E50-16	61°02.6′	114°48.8′

1)—with intervals a–e_3 being clearly recognizable except where interval a is missing. The other cores in which this stratigraphy was attempted (E50-6, E50-12, and E50-16) are missing sediments from intervals a–e.

Another species whose downcore abundance fluctuations provide the basis of a useful stratigraphy is the diatom *Eucampia balaustium* (Clarke, Burckle, and Morley 1979). However, caution must be exercised in interpreting these abundance patterns. Where currents are strong, the large size and the robustness of this diatom may cause it to form a lag deposit that is not truly representative of its actual abundance (Kellogg, Truesdale, and Osterman 1979).

The downcore fluctuations of *E. balaustium*, designated as intervals a–g, have been correlated with the oxygen isotope stratigraphy for the last 190,000 years (Weaver 1979). In the present study, the *E. balaustium* stratigraphy is well developed in four cores (E49-3, E49-24, E49-16, and E50-9; figure 2), with major abundance increases at intervals b and f and a smaller abundance increase at interval d. Intervals c and e, which are abundance minima, are somewhat more difficult to discern, especially for cores that have high sedimentation rates. In cores E50-6, E50-10, E50-12, and E50-16, however, the first intervals encountered were f or g, due to the fact that younger sediments are missing.

Several authors (e.g., Watkins and Kennett 1971) have given evidence of numerous unconformities in the southeast Indian Ocean, caused by swiftly moving and still active currents (Kolla et al. 1976). This study reaffirms the importance of current activity in this area, since sediments younger than stage f in cores E50-16, E50-12, E50-10, and E50-9 are missing. A glance at a core location map (Cassidy et al. 1977) shows that the geographic spread of these cores is regional in extent. Clearly, this area is affected by swiftly moving currents, most likely caused by eastward-flowing bottom water (Kolla et al. 1976).

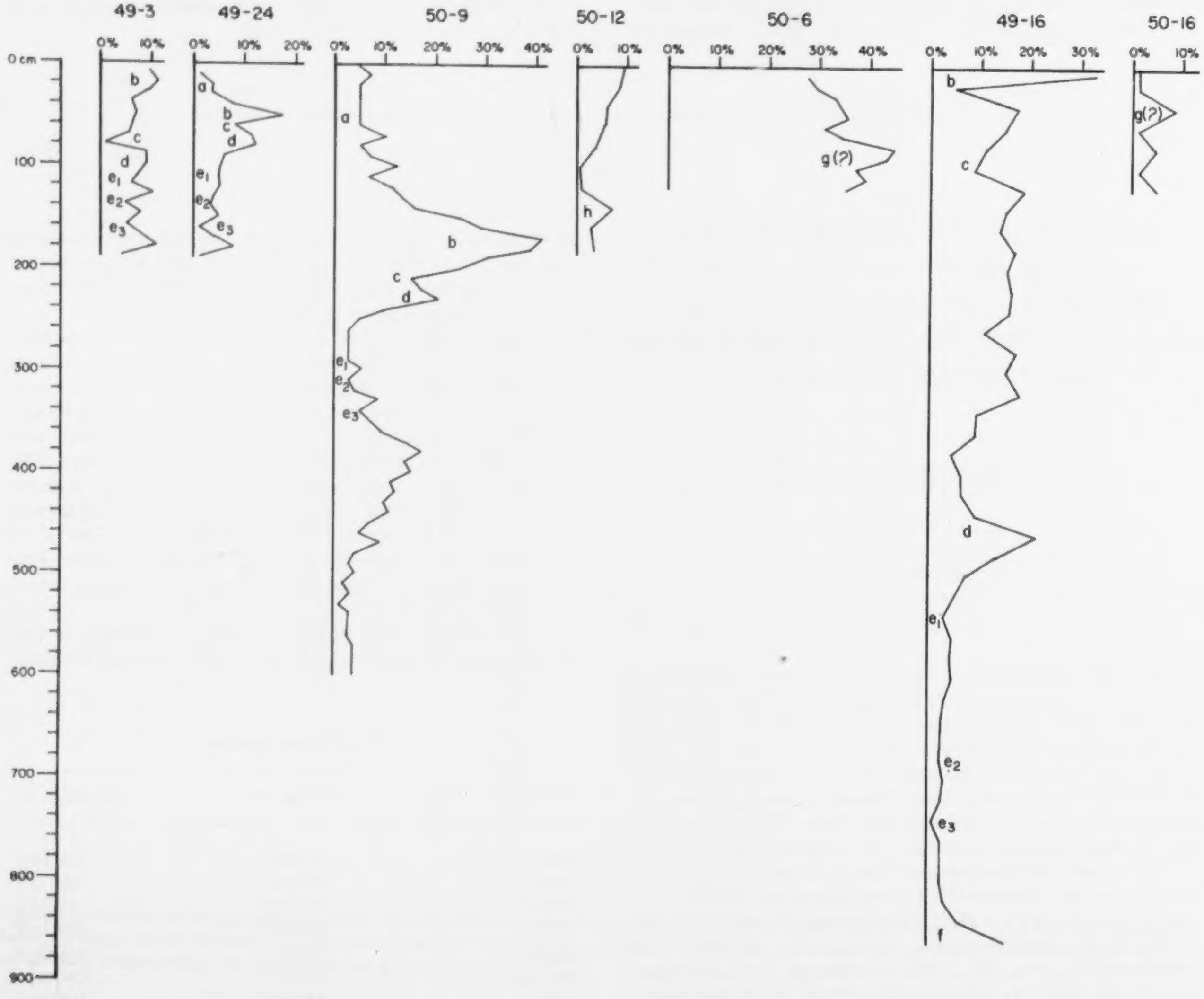

Figure 1. *Cycladophora davisiana* stratigraphy. *C. davisiana* appears to reach a peak at about 18,000 years before present and a low at about 125,000 years before present (interval e_3).

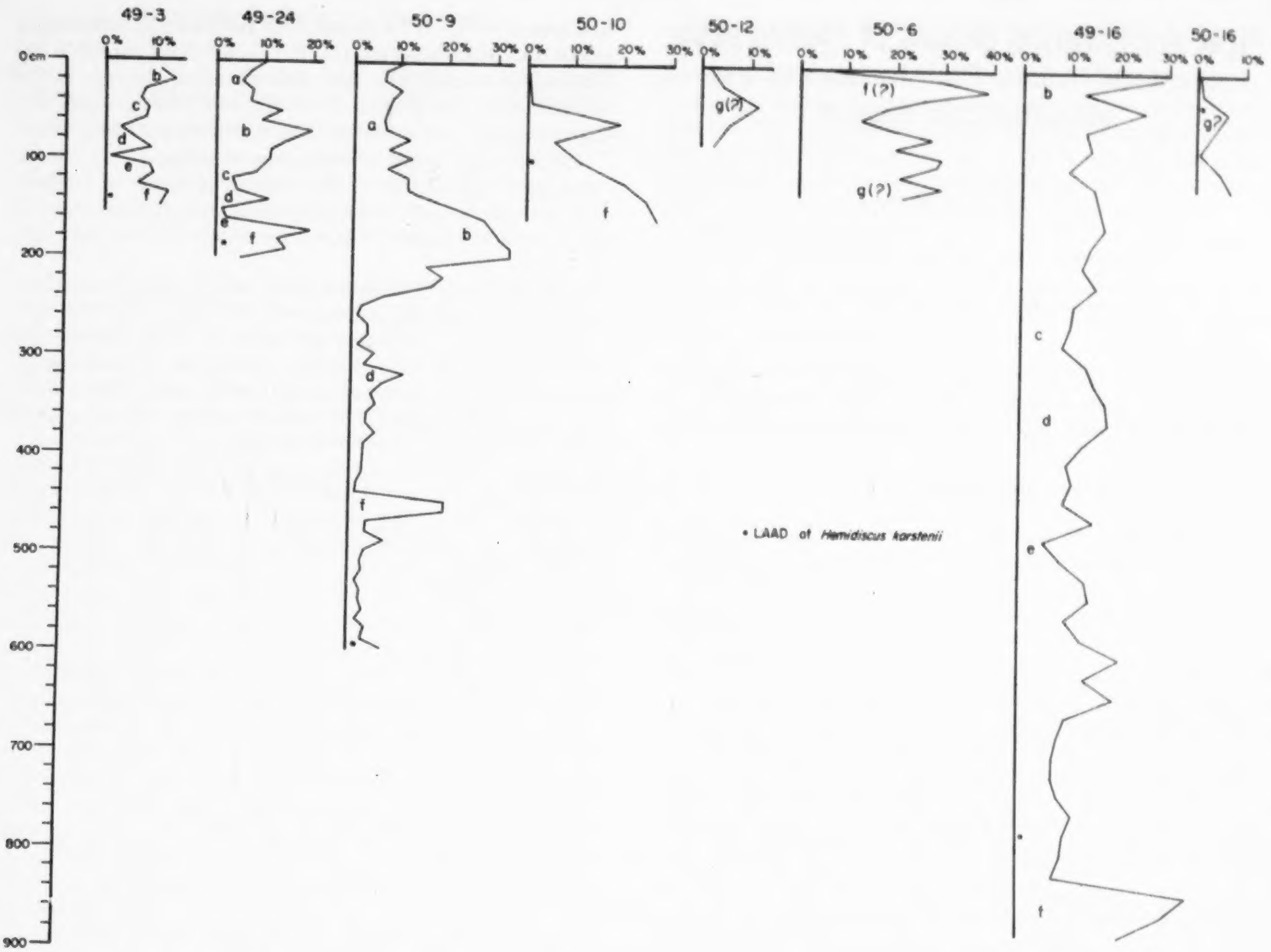

Figure 2. ***Eucampia balaustium*** **stratigraphy. Interval b, which marks a major increase in abundance, is dated at about 13,000 to 15,000 years before present. The last-abundant-appearance data (LAAD) for** ***Hemisdiscus karstenii*** **is dated at 195,000 years before present.**

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First appearance datum of *Hemidiscus karstenii* in late Pleistocene of the subantarctic region

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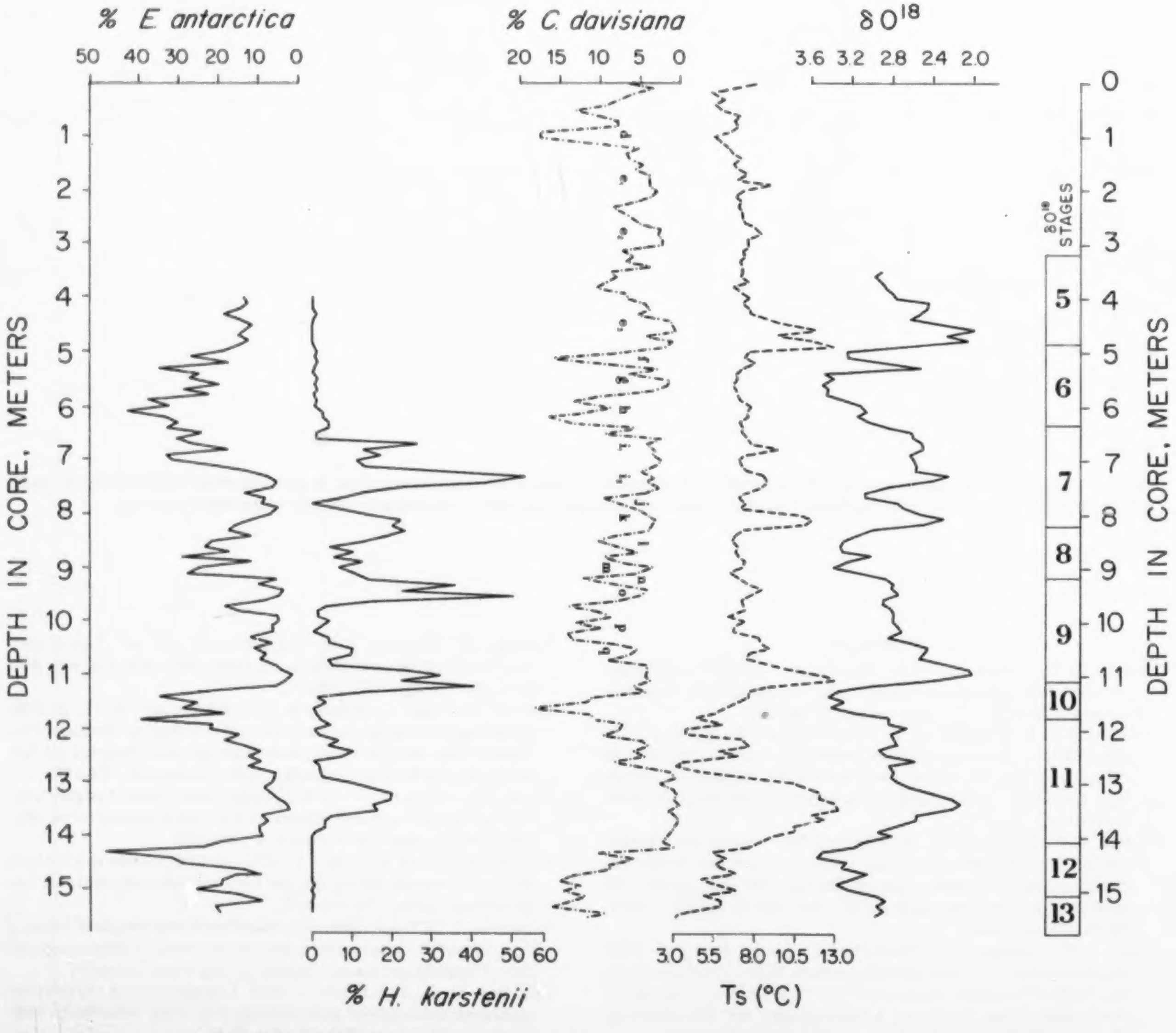
Basic to any study of the Pleistocene paleoclimatic and paleoceanographic history of the southern ocean is recognition of reliable datum levels. Without these, it is difficult to resolve time to within the 500- to 5,000-year limit necessary to differentiate glacial and interglacial modes. In two previous papers, a late Pleistocene stratigraphy was defined using changes in the abundance of the diatom *Eucampia antarctica* (Burckle and Cooke in press), and a level near the end of oxygen isotope stage 7 (195,000 years before present) was identified using the last abundant appearance of the diatom *Hemidiscus karstenii* (Burckle, Clarke, and Cooke 1977). Here I report on still another datum level for middle Pleistocene sediments of the subantarctic region.

Although *H. karstenii* first appears in the subantarctic in the late Miocene (Burckle and Opdyke 1977; Schrader 1976), it is present only in very low abundances until the middle Pleistocene. I note in two piston cores from the subantarctic Indian sector of the southern ocean (E49-18 and V16-58; table) the first abundant appearance of this species at the same strat-



Core E49-18: Frequency distribution of *Hemidiscus karstenii* and *Eucampia antarctica* plotted against abundance of *Cycladophora davisiana*, estimates of summer sea surface temperature (Ts), and oxygen isotope record (latter three data sets after Hays et al. 1976). δO^{18} = change in concentration of ^{18}O isotope.

Piston core locations and descriptions

Core number	Latitude	Longitude	Depth (meters)	Core length (centimeters)
E49-18	46°03.0′S	90°09.3′E	3,558	1,676
V16-58	46°30.0′S	31°16.0′E	4,731	1,283

igraphic level. As the figure shows, *H. karstenii* first appears in abundance in core E49-18 at the base of oxygen isotope stage 11 at approximately 421,000 years before present (Morley and Hays 1981). I find this appearance at the same stratigraphic level in V16-58. At present I have no evidence regarding the first appearance of this species south of the Polar Front.

In addition to the frequency distribution of *H. karstenii*, the figure also shows the frequency distribution of the diatom *Eucampia antarctica* and the radiolarian *Cycladophora davisiana*, as well as the oxygen isotope record and the summer sea surface temperature (Ts) based on radiolaria. The latter three data sets are from Hays and others (1976). *E. antarctica* is predominantly a colder water form, usually found south of the Polar Front. The fact that the abundance curve of this species is out of phase with that of *H. karstenii* suggests that the latter species is a warmer water form. This is supported by a direct comparison of *H. karstenii* abundance with the isotopic record and with the paleotemperature record. Maximum abundance of this species occurs in oxygen isotope stages 11, 9, and 7. The temperature curve shows that summer temperatures are generally lower before oxygen isotope stage 11. Further, the *H. karstenii* abundance curves show peaks at or near the maximum summer temperature. Thus, it would seem that this species reached its first abundance peak at the time of maximum warming in oxygen isotope stage 11 and made its final drop in abundance with the onset of cooling at the end of oxygen isotope stage 7.

Because precisely defined high-resolution datum levels are an essential background to paleoclimatic and paleoceanographic studies in the southern ocean, future work on Pleistocene diatom biostratigraphy in this region clearly must focus on this objective. Extension of the *H. karstenii* first-appearance datum south of the Polar Front is an important goal. Further, it seems likely that changes in abundance of *H. karstenii* may be useful as stratigraphic markers. Future work will try to use various biostratigraphic approaches in the southern ocean to identify specific target dates for paleoceanographic analysis.

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Ross Sea marine studies

Ross Sea ammonium flux experiment

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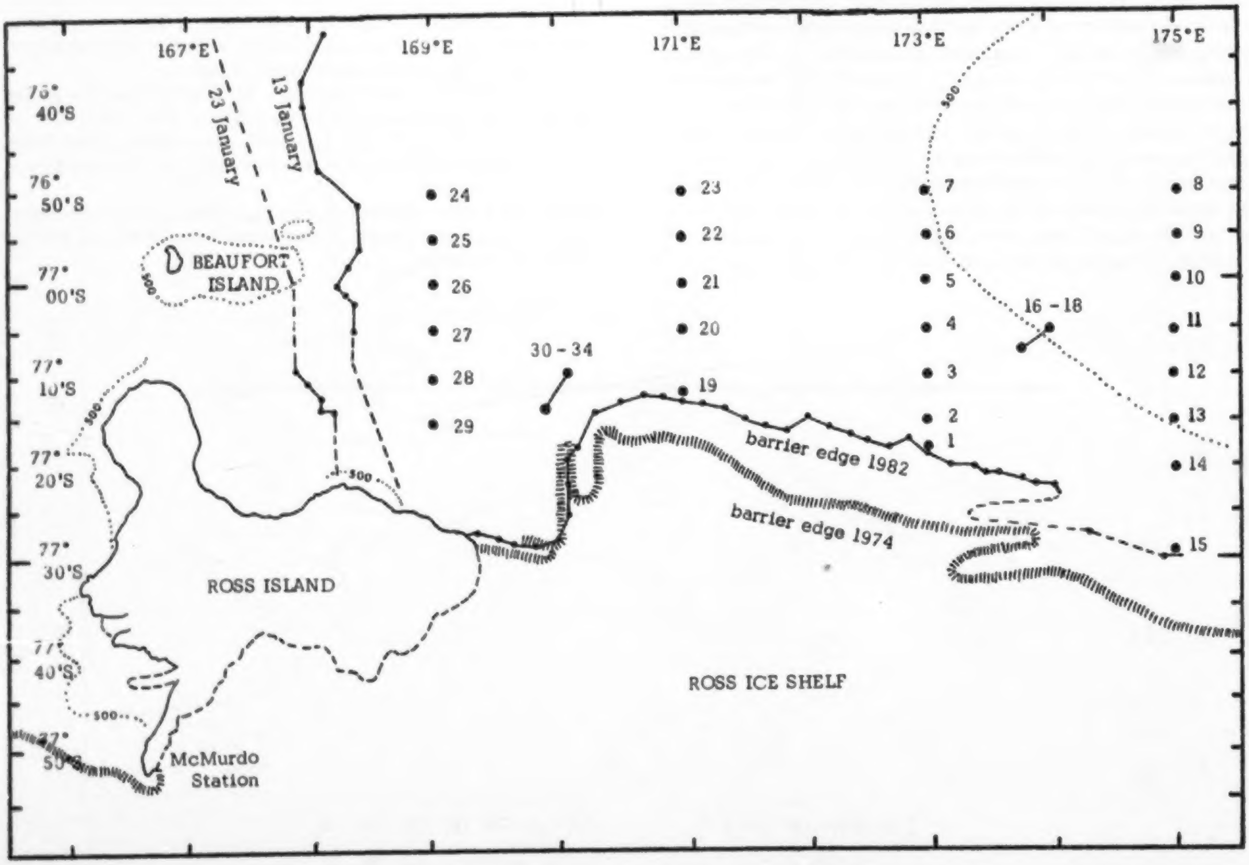
From 17 to 24 January 1982, 11 ocean scientists from Texas A&M University, Scripps Institution of Oceanography, University of Texas, University of Tokyo, and University of California-Santa Barbara carried out an interdisciplinary biological, chemical, and physical oceanographic study of the southwest Ross Sea. The cruise track and station schedule were designed to define summertime fine scales of temporal and spatial variability in water column ammonium (NH_4^+) and investigate the


167°E
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175°E
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76° 50'S
77° 00'S
77° 10'S
77° 20'S
77° 30'S
77° 40'S
77° 50'S
23 January
13 January
BEAUFORT ISLAND
500
24
25
26
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15
barrier edge 1982
barrier edge 1974
ROSS ISLAND
ROSS ICE SHELF
McMurdo Station

Figure 1. Oceanographic stations occupied during *Glacier* cruise 2, 17–24 January 1982, as part of the Ross Sea ammonium flux experiment. Stations 16–18 and 30–34 were sets of time-series observations, where pumped hydrocasts were taken following the drift track of a surface buoy drogued to a depth of 100 meters. The field area was in open water; the retreating edge of the sea ice pack on 13 January and 23 January is shown.

NH_4^+ content of the ice shelf water that flows northward into the open Ross Sea from beneath the Ross Ice Shelf.

A previous biological survey of the Ross Sea (El-Sayed et al. 1978) had encountered extensive blooms of planktonic algae along the barrier edge of the Ross Ice Shelf, extending from 167°E to 164°W. Within algal blooms, NH_4^+ concentrations were less than 0.2 microgram-atom per liter to depths of 70–100 meters but reached 0.6–1.4 microgram-atoms per liter immediately below (Biggs 1982). Since NH_4^+ promotes and regulates nitrogen-based primary production in the southern ocean (Glibert, Biggs, and McCarthy 1982; Olson 1980), it is of interest to determine the origin of the subsurface NH_4^+ maximum and to investigate how much of this reservoir of NH_4^+ may flux into the photic zone by physical processes including advection, internal waves, and Ekman pumping.

The continental ice of the Ross Ice Shelf and the water immediately beneath it at Ross Ice Shelf Project drill site J–9 are high in NH_4^+ (Horrigan 1981; Jacobs, Gordon, and Ardai 1979). We theorized that outflows of ice shelf water along the barrier edge also should have a high NH_4^+ content. The literature shows that filaments of ice shelf water at the barrier edge can be injected near the surface (see figure 1 in Jacobs, Gordon, and Amos 1979). We hypothesized that injection might be relatively common in space and time along the barrier edge if injection were forced by wind-driven upwelling and/or by thermohaline tracking along isopycnal surfaces over the denser high-salinity shelf water. The latter water mass comprises most of the midwater and deep water in the southwest Ross Sea (see Jacobs, Amos, Bruchhausen 1970).

Beginning at the barrier edge of the Ross Ice Shelf, we transected the southwest Ross Sea with four lines of salinity-temperature-depth-nutrient chemistry hydrocast stations sited meridionally along 169°E, 171°E, 173°E, and 175°E (figure 1). Stations extended seaward to 76°50′S, spaced roughly every 5 minutes of latitude. Bottom depths ranged from 575 to 950 meters along the three westerly transects; station depths along the easternmost transect shoaled to 320–450 meters over Pennell Bank.

In January 1982, the barrier edge of the Ross Ice Shelf extended some 10–15 kilometers farther north than had been reported in 1974 and rose 20 meters above sea surface (figure 2). Assuming that the ice of the seaward edge of the Ross Ice Shelf has an average density of 0.857 and is floating isostatically, its subsurface mass would extend to a depth of about 130 meters. In fact, rosette bottle samples—which were tripped every 20 meters within the upper 100 meters and at 125, 150, 200, and 250 meters—demonstrated sharply defined subsurface maxima of NH_4^+ at depths of 120–140 meters at the barrier edge (figure 3). Isopleths of NH_4^+ generally sloped upward and decreased in concentration from this point. The raw salinity data suggest a correspondence between these NH_4^+ gradients and local density surfaces, although assignment of this NH_4^+ to a source of ice shelf water must await final processing of the salinity-temperature-depth data (Amos, *Antarctic Journal*, this issue).

At two locations, the subsurface NH_4^+ maximum was drogued and then time-series-sampled by following the drift path of a surface buoy. These time series stations (casts 16–18 and 30–34 in figure 1) contrasted an easterly zone of high phytoplankton biomass with a westerly area of lower chlorophyll concentrations; biogenic turnover rates of NH_4^+ in these two locations were estimated *in vitro* by shipboard uptake of $^{15}NH_4^+$ and $^{15}NO_3^-$ (stable mass isotopes of ammonium ion and nitrate ion, respectively) under several regimes of light and nutrient enrichment (Holm-Hansen, Neori, and Koike, *Antarctic Journal*, this issue). Short-term temporal variability (minutes-to-hours scale) in pumped profiles of ambient NH_4^+ was investigated in relation both to concurrent variation in temperature, salinity, and sigma-theta and to variation in dissolved oxygen and other inorganic nutrients (Johnson and Amos, *Antartic Journal*, this issue). Ammonium excretion and grazing pressure of the zooplankton standing crop were estimated biochemically from samples collected with BONGO nets. In addition, the effect of starvation on the extractable protein content, NH_4^+ excretion, and glutamate dehydrogenase activity of *Euphausia crystallorophias* was investigated (Bidigare and Cox, *Antarctic Journal*, this issue).

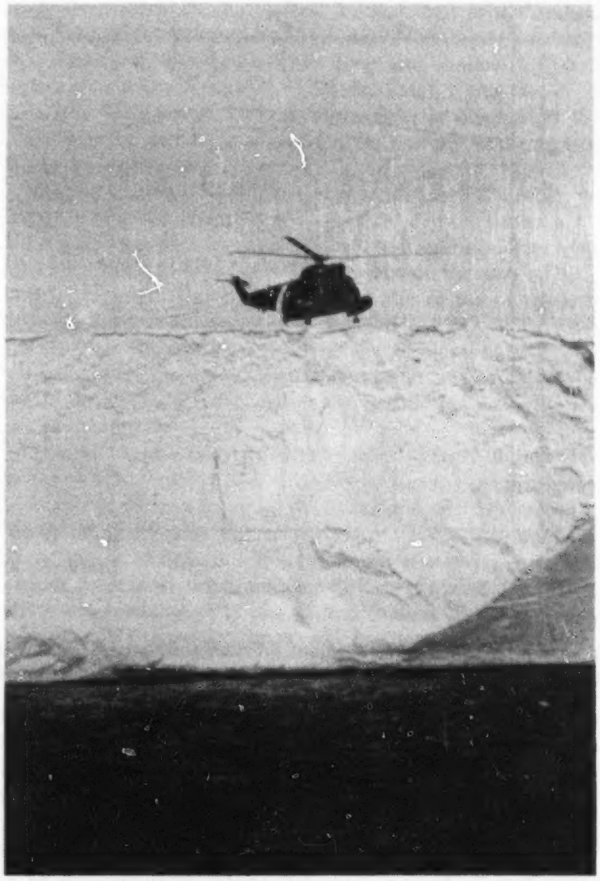

Figure 2. A Coast Guard helicopter hovers atop the barrier edge of the Ross Ice Shelf. At its seaward terminus, the Ross Ice Shelf rises 20 meters above sea level and extends some 120–140 meters below the sea surface.

We thank Captain J. W. Coste, the other officers, and the marine science technicians of USCGC *Glacier* for their keen interest in and outstanding logistic support of this research program. Texas A&M marine technicians J. D. Guffy and M. A. Spears provided round-the-clock shipboard autoanalyzer support. Texas A&M University contributions to this research were supported by National Science Foundation grant DPP 79-21355.

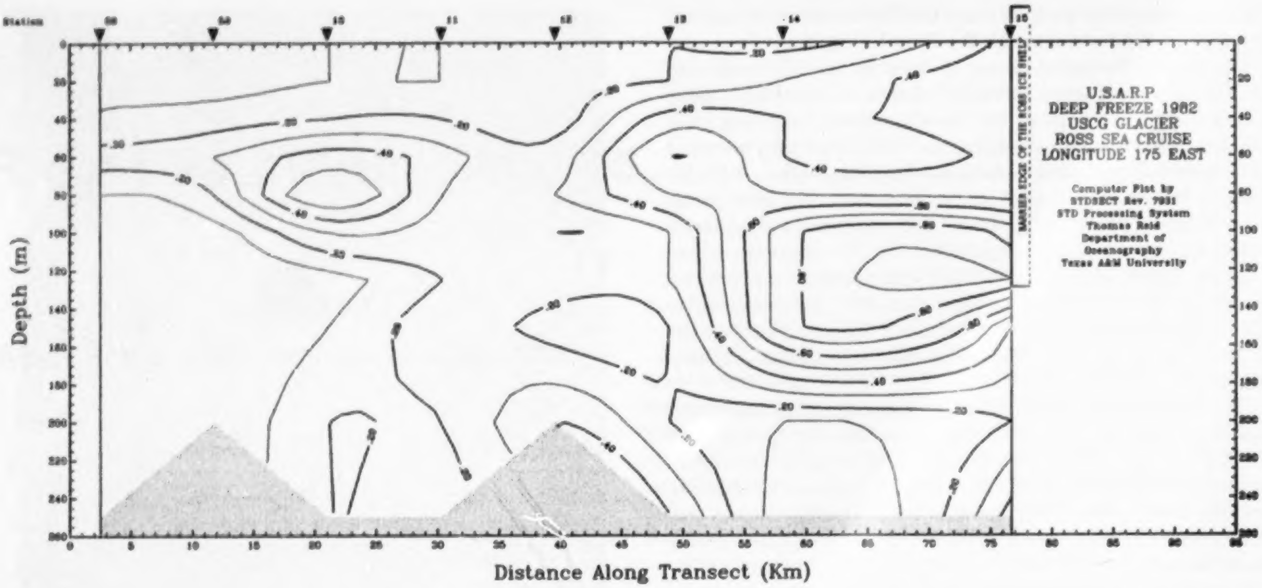

Figure 3. Ammonium concentrations (in microgram-atoms per liter) in the upper 250 meters along a 64-kilometer (40-mile) transect seaward from the barrier edge of the Ross Ice Shelf at 175°E. Shaded area denotes absence of bottle samples; see figure 1 for station locations.

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Physical oceanography of the southwestern Ross Sea, January 1982

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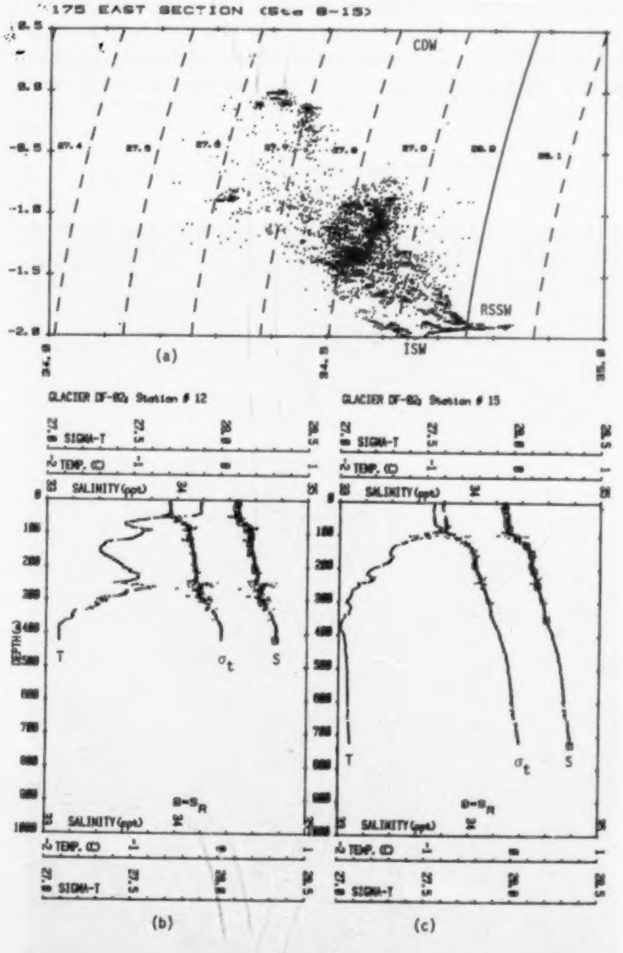
During the Ross Sea ammonium flux experiment (see Biggs, *Antarctic Journal*, this issue), the regional oceanography of the southwestern Ross Sea was investigated by making surface-to-bottom and time-series salinity/temperature profiles (Johnson, Biggs, and Amos, *Antarctic Journal*, this issue) with a salinity-temperature-depth (STD) sensor.

Twenty-eight vertical stations and two main time-series stations were occupied (see station map in Biggs, *Antarctic Journal*, this issue). Five additional stations were occupied along the sea ice edge in McMurdo Sound to compare with a similar section I made in 1979 (see Jacobs et al. 1981). The present investigation was done aboard USCGC *Glacier* during Deep Freeze 82, using a

Plessey model 9040 STD system with a 12-bottle (2.5-liters each) rosette sampler. Discrete samples were taken with the rosette at 5, 20, 40, 60, 80, 100, 125, 150, 200, and 250 meters, primarily to provide nutrient and chlorophyll data for the ammonium flux experiment, but also for dissolved oxygen determinations and calibration of the STD salinity sensor. Two other samples, at middepth and just off the bottom, were routinely collected for STD calibration. Bottom depths ranged from 357 to 947 meters, and the STD was lowered to within a few meters of the bottom with the aid of a pinger. Thermometry was used to calibrate the STD temperature sensor. The STD sensor used, a "seasoned" veteran of numerous polar cruises, required little correction to bring it up to "water bottle" accuracy.

The oceanography of this part of the Ross Sea has been described by Jacobs, Amos, and Bruchhausen (1970), and its particular relationship to the Ross Ice Shelf by Jacobs, Gordon, and Ardai (1979). Adjacent to the ice shelf, four types of subsurface water have been identified: deep and shallow Ice Shelf Water, a modified form of Circumpolar Deep Water, and deep Ross Sea Shelf Water. A temperature/salinity diagram of the 175°E section (figure, a) illustrates the various water masses found on this cruise.



Temperature and salinity characteristics of waters along the 175°E meridian near the Ross Ice Shelf (see Biggs, *Antarctic Journal*, this issue, for station locations). (a) Composite temperature/salinity diagram, stations 8–15. CDW = Circumpolar Deep Water, RSSW = Ross Sea Shelf Water, ISW = Ice Shelf Water; salinity (horizontal axis) in parts per thousand, temperature (vertical axis) in °C; dashed lines indicate isopycnal surfaces in sigma-T units [sigma-T = (ρ − 1) × 10^3, where ρ = *in situ* density]. (b) Vertical profiles of temperature, salinity, and sigma-T (σ_t) for station 12 over the Pennell Bank; s_R = salinities from rosette samples. (c) As in (b), for station 15 adjacent to the Ross Ice Shelf face.

Modified Circumpolar Deep Water was found almost exclusively over the southern portion of the Pennell Bank on the 175°E section (station 12, figure, b), and only occasionally on the adjacent, 173°E section. It can be identified on the temperature/salinity diagram (figure, a) by the cluster of points midway between and roughly parallel to the 27.8 and 27.9 isopycnals. Whether the Pennell Bank exercises any topographical control over this water mass is not known, but stations 14 and 15 off the bank (profile, figure, c) have completely different water characteristics in the upper 300 meters.

Ice Shelf Water is characterized by the proximity of the water to the *in situ* freezing point, and it is formed by processes occurring under or adjacent to the Ross Ice Shelf. The deeper Ice Shelf Water has temperatures of less than −2°C and salinities in the range of 34.5 to 34.7‰. It is found at a depth near 400 meters, corresponding to the average base of the ice sheet. This water was found at only one station (station 15) on the easternmost (175°E) transect (figure, c), a few hundred meters away from the barrier.

The second, shallower type of Ice Shelf Water, usually found at a depth of 250 meters, was not encountered on this cruise. No temperatures of less than −1.9°C were found shallower than 250 meters. Only at station 14 did the water reach to within 0.2°C of the *in situ* freezing point at 250 meters.

Ross Sea Shelf Water was found at all stations except those over the Pennell Bank and is illustrated in the figure by the bottom water mass, temperature less than −1.9°C, salinity greater than 34.7‰.

Preliminary geostrophic calculations show flow parallel to the ice shelf face but very little flow between transects into or away from the ice shelf. Using the bottom as a level of no motion, the net transport is toward the west except on the westernmost transect (169°E), where it is toward the east. The characteristics of stations adjacent to the ice shelf and those no more than 10 kilometers away creates a considerable shear in the computed currents. That such a variability exists in a small geographical area is of considerable interest, and preliminary results reveal the important role that the ice shelf and topographic features exert on the regional oceanography. How this regime is related to the observed nutrient distribution has yet to be studied. Property/property diagrams, vertically and horizontally contoured sections, and other calculations are presently being performed on these data.

I thank the officers and crew of the USCGC *Glacier* for their help and support in carrying out this fieldwork. Particular thanks go to Captain J. W. Coste, LTJG Carla Ridnor, Master Chief Marine Science Technician P. St. Joule, and the other technicians. This work was partially supported by National Science Foundation grant DPP 79-21355 to Texas A&M University.

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Oceanographic time-series studies with an STD-submersible pump combination

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As part of the Ross Sea ammonium flux experiment, we investigated the temperature, salinity, and nutrient signature of the ice shelf water that flows northward from beneath the Ross Ice Shelf into the Ross Sea. Working with the hypothesis that ice shelf water is a principal source of subsurface ammonium (see Biggs, *Antarctic Journal*, this issue), we identified the mesoscale variability of water column ammonium along four meridional lines of Niskin-bottle cast salinity-temperature-depth (STD) and stations and contrasted this with fine-scale variability determined from hydrocasts with an STD recorder-submersible pump combination.

Following the drift path of a surface buoy drogued at 100 meters within the subsurface ammonium maximum, we pump-sampled the upper 120 meters of the water column using a Berkeley model AL-28 centripetal pump mounted to the frame of a Plessey 9040 STD recorder (see figure 1). Two vertical casts and a 2–3-hour horizontal cast were completed at each of two drogue stations. The pump pushed water to analytical equipment aboard the ship for continuous measurement of ammonium, nitrate, nitrite, silicate, dissolved oxygen, and *in vivo* fluorescence. Details of this sampling and analytical system have been given by Johnson (1981). The horizontal drift hydrocasts, during which the pump was suspended for several hours within the thermocline, generated concurrent time-series data on nutrients, chlorophyll, temperature, and salinity.

Ship drift complicates the interpretation of the time-series data. During the horizontal pump cast at station 17, the ship was pushed by surface currents and the wind at a speed of about 1 knot, whereas ship drift was only about ⅓ knot at station 33.

STD time-series data for station 17 in the east and station 33 in the west (figure 2; see figure 1 in Biggs, *Antarctic Journal*, this issue, for locations) show evidence of internal wave activity, particularly in the temperature signal. The STD recorder was held in the thermocline at depths of 68 meters (station 17) and 65 meters (station 33). The vertical temperature structure near

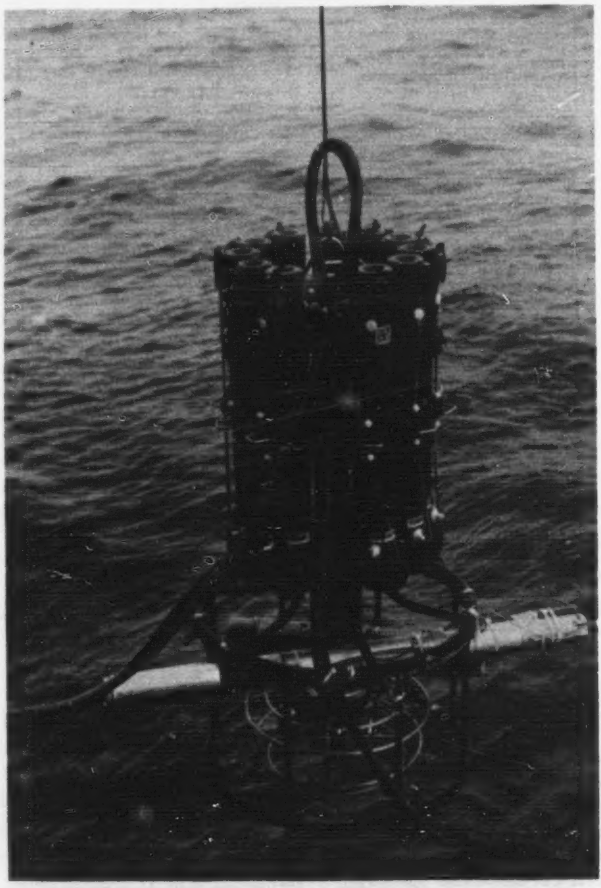

Figure 1. Submersible pump mounted to the frame of a Plessey 9040 salinity-temperature-depth recorder, showing Niskin bottles for discrete sampling and pump-hose combination for continuous sampling.

station 17 (see figure in Amos, *Antarctic Journal*, this issue) and the magnitude of the temperature excursion during this series indicate that these internal waves had amplitudes greater than 20 meters. Their periodicity is not known, but smaller, more regular peaks with periods of several minutes are superimposed on the temperature trace at all the time-series stations. The "clipping" of the temperature signal at station 33 (figure 2B) probably was caused by the traveling of internal waves along a narrow pycnocline separating two mixed layers (i.e., a step in the thermocline). This phenomenon also has been observed in time-series data taken beneath the arctic pack ice (see figure 10 in Amos 1975).

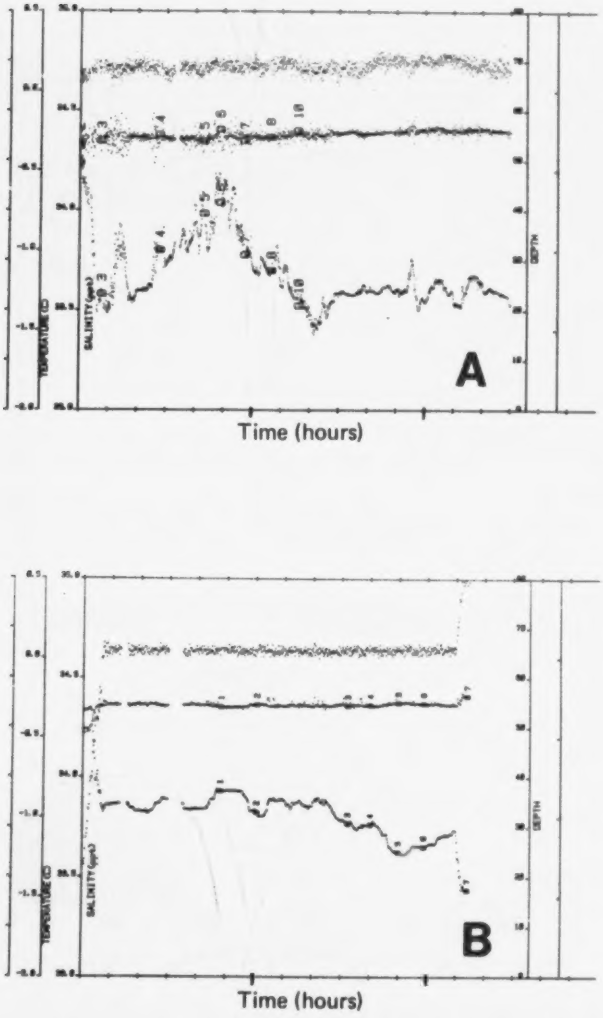

Figure 2. Time-series records at station 17 (A) and station 33 (B) showing depth (top; in meters), salinity (middle; in parts per thousand), and temperature (bottom; in degrees Celsius). Records are annotated to show collection of the water sample by rosette multisample. The time axis is marked at hour intervals, subdivided into 10-minute intervals.

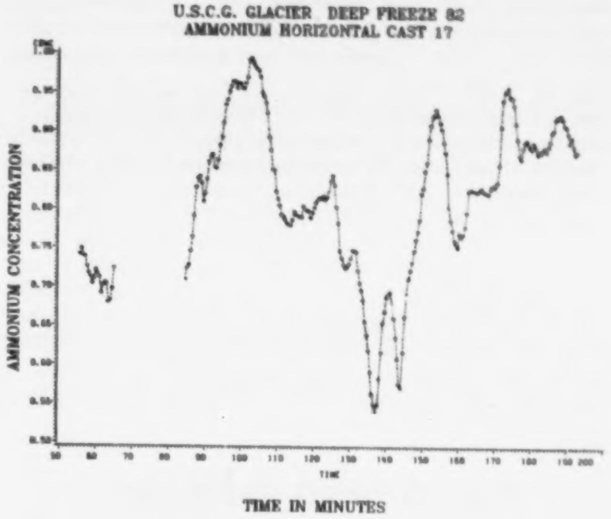

Figure 3. Time-series records of ammonium concentration, in microgram-atoms per liter, from station 17. Records are plotted at half-minute intervals and were calibrated from concurrent Niskin bottle samples.

Figure 3 shows a 2-hour ammonium time series at 65 meters from station 17. Ammonium concentrations varied with temperature and ranged from 0.5 microgram-atom per liter when temperature at 68 meters was highest to 1.0 microgram-atom per liter when temperature at 68 meters was lowest. By contrast, ammonium concentrations at this station in the 0–50-meter mixed layer were only 0.2–0.3 microgram-atom per liter. Thus, the local temperature minima in figure 2A mark locations where "patches" of high ammonium concentration, seen in figure 3, have been injected into or near the base of the mixed layer, increasing by three- to fivefold the local supply of reduced nitrogen available for phytoplankton growth and maintenance.

As at station 17, maxima of ammonium at station 33 varied with minima of temperature, ranging at 65 meters from 1.6 microgram-atoms per liter at −0.8°C to 2.0 microgram-atoms per liter at −1.3°C. However, at this station, ammonium concentrations in the mixed layer (from 0 to 50 meters) were high, ranging from 0.9 to 1.2 microgram-atoms per liter.

Silicate and oxygen records also showed wavelike fluctuations within the thermocline, although the peak-to-peak amplitudes were smaller than those of ammonium. Nitrate and nitrite concentrations remained rather constant; gradients in these more oxidized forms of inorganic nitrogen were small within the range of the thermocline.

The regional physical oceanographic study (see Amos, *Antarctic Journal*, this issue) showed that, beneath the thermocline, both warm water cores and cold ice shelf water entered the eastern part of the study area. The colder, ammonium-rich water tends to be similar to ice shelf water in physical properties such as temperature and salinity. However, the higher temperature, lower ammonium water is more similar in temperature and salinity to antarctic surface water than to the warm, subsurface water masses found by us and by others (e.g., Jacobs, Gordon, and Ardai 1979) along the Ross Ice Shelf edge.

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Phytoplankton distribution, biomass, and activity in the southwest Ross Sea

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Our work on the USCGC *Glacier* in January 1982 had three basic objectives: to obtain data relevant to the ammonium flux experiment as described by Biggs (*Antarctic Journal*, this issue); to continue our investigation of physiological adaptations of phytoplankton to environmental conditions; and to increase our understanding of the dynamics of the initial stages of the food web in antarctic waters. Water samples were obtained at 26 stations in open water northeast of Ross Island; in addition, samples were taken from the surface to 130 meters, by means of a profiling pump system, at eight locations along the drift track of a drogued surface buoy (see Biggs, figure 1, for station locations).

Phytoplankton distribution and biomass. Recent work (Glibert, Biggs, and McCarthy 1982; Koike, Rönner, and Holm-Hansen 1981; Olson 1980) has shown that 50 to 90 percent of the nitrogen assimilated by phytoplankton in the Antarctic is derived from ammonia. Most of the remainder is furnished by nitrate, but urea, nitrite, and dissolved organic compounds also are used. Although ammonia is the preferred nitrogenous nutrient for antarctic phytoplankton, it is not known if ammonia has a significant effect on either the rate of primary production or species composition. During the ammonium flux experiment, we wanted to determine the distribution, biomass, and species composition of the phytoplankton crop relative to the availability of ammonia.

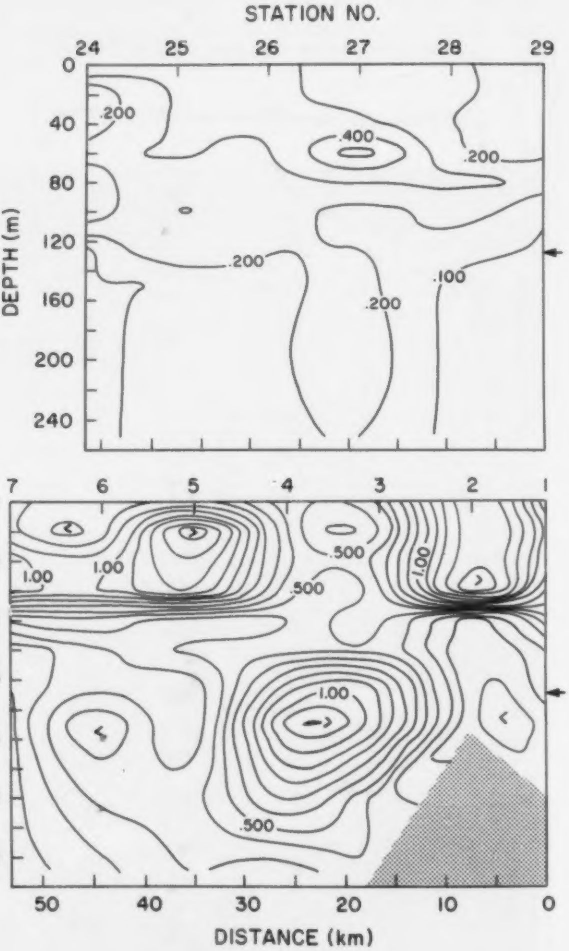

Figure 1. Contours of chlorophyll *a* (micrograms per liter) along transects centered on 169°E longitude (upper section) and on 173°E longitude (lower section). Arrows to the right of each section indicate approximate depth of the Ross Ice Shelf, which was a few hundred meters to the south of stations 1 and about 16 kilometers from station 29. Shaded area denotes absence of bottle samples.

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Chlorophyll and phaeophytin were determined by fluorometric techniques at 12 depths at all of the stations. Phytoplankton biomass was highest at the two eastern transects and lowest at the westernmost transect. From east to west, the average chlorophyll *a* concentration in the upper 60 meters of the water column of the four transects averaged 0.9, 1.1, 0.5, and 0.25 microgram per liter. Chlorophyll concentrations in the upper 250 meters for two of these sections (stations 1–7 and 24–29) are shown in figure 1. Data for stations 1–7 (figure 1, lower section) and 8–15 revealed a zone of high chlorophyll concentration centered at a depth of about 150 meters; this was well below the euphotic zone, which averaged 30–40 meters for these sections.

Water samples were preserved with Lugol's iodine solution at many of our stations for floristic analysis by inverted microscope techniques. The biomass and species composition of the phytoplankton crop will be anlayzed with regard to the distribution of nutrients and to physical data from the four sections (see Amos, *Antarctic Journal*, this issue).

Carbon and nitrogen metabolism. Water samples were obtained at stations 8, 10, 23, 29, and at both "pump" stations (stations 16–18 and 30–34) for metabolic studies using both radiocarbon (^{14}C) and the stable isotope of nitrogen (^{15}N). Sampling depths were approximately 2 meters, 10–20 meters (10 percent light level), and 30–50 meters (3 percent light level). Water samples for ^{15}N and ^{14}C studies were obtained from the same 30-liter Niskin bottle. Experiments were done in identical incubation vessels (either 1.0-liter borosilicate glass or 4.0-liter polycarbonate bottles) and incubated together in temperature- and light-controlled incubation units on the forward deck of the ship. Solar radiation (400 to 700 nanometers) was monitored

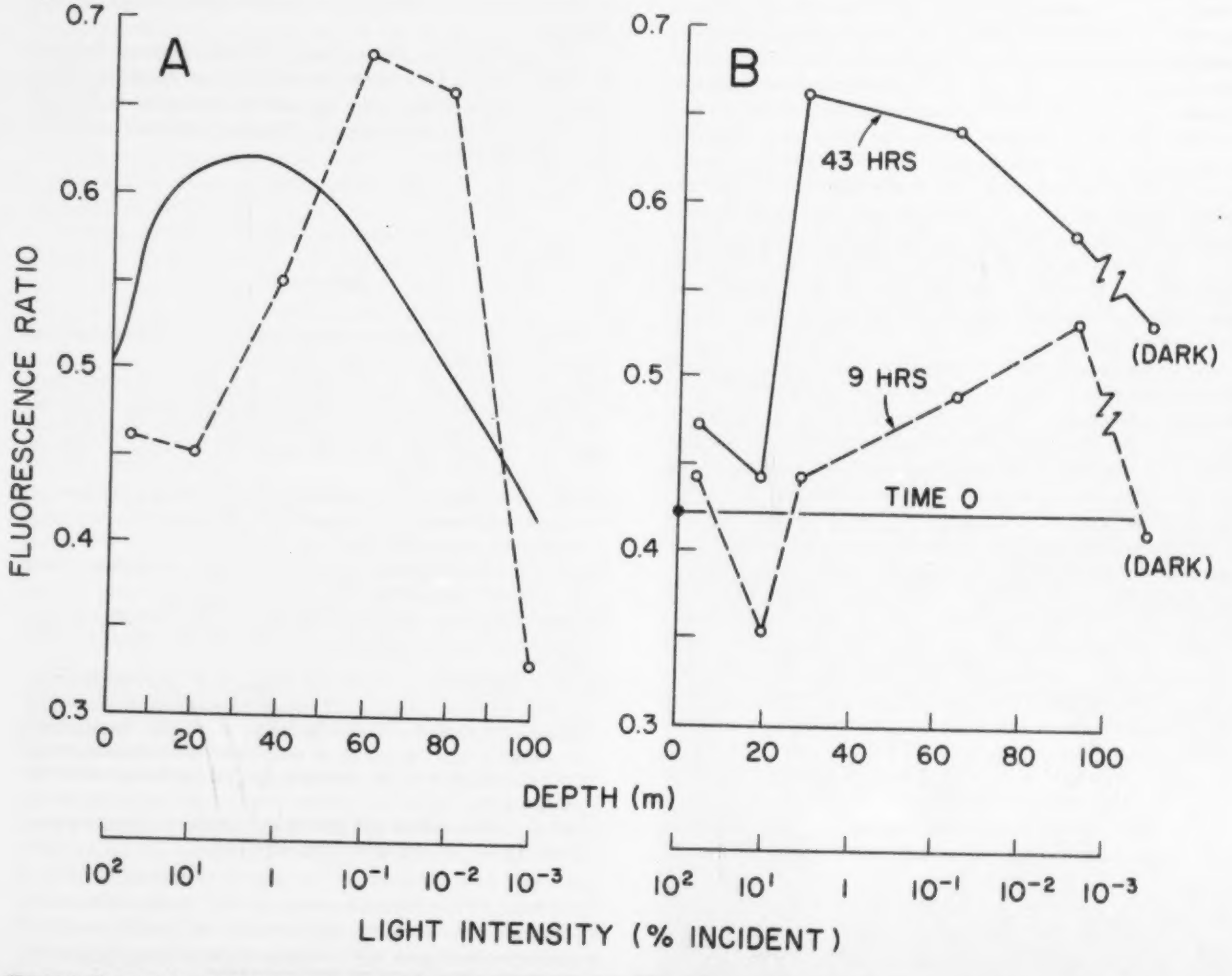

Figure 2. Physiological adaptation of phytoplankton cells to varying light intensities as indicated by relative effectiveness of blue and green light in activating *in vivo* chlorphyll *a* fluorescence. The ordinate (fluorescence ratio) is defined as the fluorescence induced by green light (475–575 nanometers) divided by the fluorescence induced by blue light (350–450 nanometers). A: The fluorescence ratio of cells pumped from the upper 100 meters (continuous line), and that determined on discrete samples taken from Niskin bottles (dashed line). B: Time response of the change in the fluorescence ratio of cells (surface sample) when exposed to varying light intensities.

continuously with a deck-mounted scalar irradiance quantum meter; the light flux within the experimental bottles was measured with a small, integrating irradiance meter. Total particulate organic carbon and nitrogen were measured in all water samples by CHN gas chromatographic techiques.

Experiments with ^{15}N-enriched substrates included (1) absolute nitrogen uptake rates from ammonia, nitrate, and urea as a function of light intensity, (2) time sequence of assimilation between 6 and 80 hours, and (3) uptake rates in size-fractionated samples (less than 10 micrometers, less than 75 micrometers, and unfractionated sample). The radiocarbon experiments were identical to the nitrogen experiments except that ^{14}C-bicarbonate was used instead of the ^{15}N-enriched nitrogen substrates. Chlorophyll also was measured in all samples, so that carbon and nitrogen assimilation rates can be expressed as a function of both chlorophyll concentration and absolute light flux incident upon the cells. All ^{15}N samples will be processed by mass spectrometry at the University of Tokyo (by I. Koike) in late 1982.

Phytoplankton adaptation to varying light intensity. The upper mixed layer in antarctic waters often extends much deeper than the euphotic zone. Hasle (1956) suggested that this limits phytoplankton biomass and primary production, since cells will be mixed below the euphotic zone. To assess the importance of this phenomenon, it is necessary to know something about the rate at which cells are "circulating" within the mixed layer. We have measured the *in vivo* action spectra for chlorophyll *a* fluorescence of cells from various depths in the water column to help determine both residence time at depth and physiological adaptations to the existing light fields. Previous experiments in the Scotia Sea and in coastal California waters (Neori et al. 1982) have indicated that cells from deep in the euphotic zone use green light for photosynthesis more effectively than do cells from surface waters.

During the two "pump" stations in the Ross Sea, we passed the pumped water (0 to 130 meters depth) through two fluorometers, one having excitation light peaking in the blue portion of the spectrum (about 440 nanometers) and the other, in the green portion of the spectrum (about 550 nanometers). Data from both instruments were recorded and processed by a desktop computer to give us an index of how efficiently blue and green light activate chlorophyll *a* fluorescence. Cells from 20-50 meters depth show much more chlorophyll *a* fluorescence by green light than do cells from surface waters, (figure 2A, page 151, solid line). During the pumped profile, water samples were taken at six depths, filtered onto glass fiber filters, frozen, and returned to our laboratories at Scripps Institution of Oceanography for determination of corrected action spectra for chlorophyll *a* fluorescence in a recording spectrofluorometer. The results (figure 2A, dashed line) also show increasing use of green light by deeper samples, followed by a decline at depths below the light-compensation point.

We do not know how long it takes for cells to show this "green light" adaptation in regard to activation of chlorophyll fluorescence. As a start on this problem, we took surface water from the first pump station and incubated subsamples at five different light intensities as well as at "no light." After 9 and 43 hours in the deck incubators, samples were filtered and the action spectra for chlorophyll fluorescence were determined in the same manner as were the discrete samples shown in figure 2A. A significant response was detected after 9 hours of incubation, but the response was much greater after 43 hours (see figure 2B). Data from such culture experiments, coupled with data on the action spectra for cells in the upper water column, should provide some limits for the rate at which phytoplankton cells are "circulating" in the mixed layer.

Microzooplankton sampling. One of the unanswered questions regarding the food web structure and nutrient cycling in the Antarctic is the role of microzooplankton. To define microzooplankton abundance and population structure, samples were collected by the method used by Beers, Reid, and Stewart (1975) at 10- or 25-meter intervals from the surface to 100 meters at the two "pump" stations. These samples have been delivered to John R. Beers at Scripps Institution of Oceanography for analysis.

Participants on the ship included O. Holm-Hansen, I. Koike, A. Neori, and C. D. Hewes. We thank Texas A&M University personnel for processing the computer-drawn plots in figure 1. This research was supported by National Science Foundation grant DPP 80-20242.

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Zooplankton metabolic studies in the Ross Sea

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During the period 17–24 January 1982, we participated in an interdisciplinary study aboard USCGC *Glacier* to define the important environmental and biological factors regulating primary and secondary production in the southwest Ross Sea. Biggs (*Antarctic Journal*, this issue) has presented an overview of the expedition. Our primary interest was to estimate the impact of ammonium excretion and the grazing potential of the zooplankton community, using physiological and biochemical measurement techniques. In addition, we investigated the effects of short-term starvation on the nitrogen metabolism of *Euphausia crystallorophias*.

Zooplankton were sampled at every other station using 70-centimeter BONGO nets (figure) of 333-micrometer mesh hauled vertically from 100 to 0 meters (see Biggs, figure 1, for location of stations). Flow through the nets was estimated using a TSK flowmeter; calibration data were provided by E. Brinton. Volumes filtered ranged from 70 to 230 cubic meters per haul. The contents of one of the nets were frozen for biochemical analysis; the contents of the other were preserved in buffered formaldehyde for subsequent taxonomic identification and wet-weight determination.

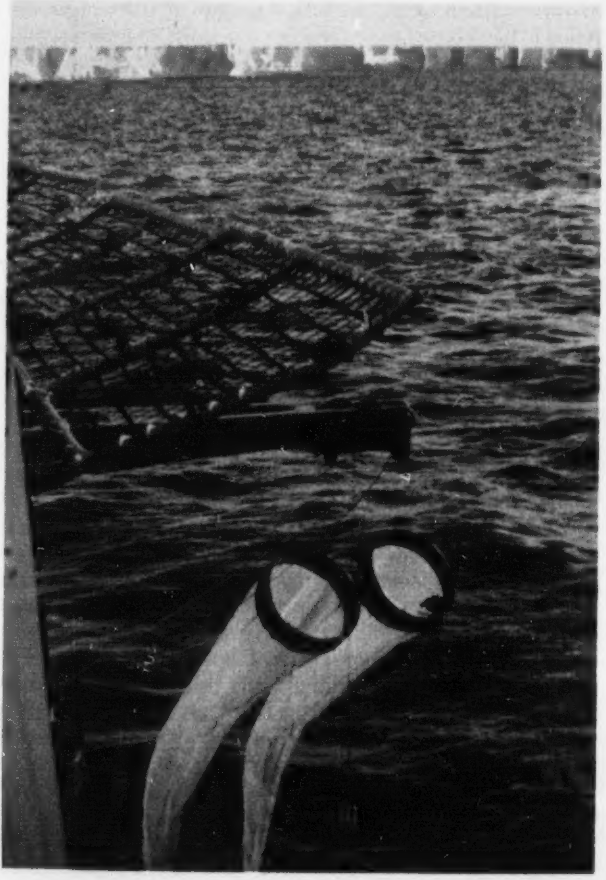
Zooplankton samples were dominated by copepods, thecosome pteropods, and juvenile euphausids. The 333-micrometer mesh retained quantities of diatoms, with algal displacement volumes reaching tens to hundreds of milliliters per haul in the eastern part of our field area. Preserved zooplankton currently are being sorted for wet-weight measurement. Their biomass (in grams per cubic meter) will be used in conjunction with the weight-specific excretion data from previous studies of Ross Sea zooplankton (Biggs 1982b) to map the zooplankton excretion impact (in micromoles of ammonium per cubic meter per hour) throughout our field area.

To estimate the grazing potential of the zooplankton community, laminarinase activity assays will be performed on subsamples of the material frozen for biochemical analysis. Cox (1981) found that laminarinase activity was useful as an index of grazing potential in temperate euphausids and temperate mixed zooplankton. Laminarinase activities will be normalized by volume filtered per haul and then compared with the average chlorophyll concentration at each of the zooplankton sampling stations.

The effect of starvation on the nitrogen metabolism of *E. crystallorophias* was investigated by measuring changes in protein content, rates of ammonium excretion, and glutamate dehydrogenase activity after 2 days of maintenance in filtered seawater. Previous studies have shown that glutamate dehydrogenase activity is linked to rates of ammonium excretion in temperate crustaceans (Bidigare and King 1981), subtropical zooplankton (Bidigare, King, and Biggs in press), and antarctic zooplankton (Bidigare et al. 1981). The table presents the results of the starvation experiment. Adult euphausids averaging 200 milligrams in wetweight were used.

Immediately after capture, excretion rates averaged 0.14 micromole of ammonium per individual per hour, equivalent to the values that Biggs and Bidigare (1981) and Biggs (1982b) predicted for euphausids collected in the Scotia Sea and the Ross Sea, respectively. Excretion rates decreased significantly ($p = 0.037$), by an average of 57 percent, after the 2-day starvation period. Body protein also decreased signficantly ($p = 0.003$), by an average of 24 percent in 2 days. Catabolism of body protein provides a source of energy in the form of adenosine triphosphate and a means of satisfying metabolic nitrogen requirements during short-term starvation. Ikeda and Skjoldal (1980) reported decreases of 33 percent and 34 percent in the ammonium excretion and protein content of subtropical copepods maintained for 2 days in laboratory aquaria.

Glutamate dehydrogenase activities measured in *E. crystallorophias* also decreased significantly ($p = 0.032$), by an aver-



The BONGO net system used aboard USCGC *Glacier* to collect zooplankton samples.

Effect of short-term starvation on the nitrogen metabolism of *E. crystallorophias*

	Days of starvation[a]	
	0	2
Protein content (milligrams per individual)	19.4 ± 0.3 (2)	14.8 ± 0.2 (2)
Ammonium excretion rate (micromoles of ammonium per individual per hour)[b]	0.14 ± 0.01(2)	0.06 ± 0.02(2)
Glutamate dehydrogenase activity (micromoles of ammonium per individual per hour)[c]	13.6 ± 0.8 (2)	9.6 ± 0.6 (2)

[a] Figures show means ± 1 standard deviation; figures in parentheses are numbers of experiments performed.

[b] Measured at 0°C; 3–6 individuals per experiment.

[c] Measured at 10°C; 3–6 individuals per experiment.

age of 29 percent. This confirms the finding that glutamate dehydrogenase activities are linked to rates of ammonium excretion in boreal crustaceans and extends to the southern ocean environments the utility of glutamate dehydrogenase as an index of ammonium excretion.

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Marine biology

Development of the sea ice microbial community in McMurdo Sound

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While sailing on Her Majesty's Discovery ships *Erebus* and *Terror* during the years 1839–43, J. D. Hooker observed rich growths of diatoms in the antarctic sea ice (Hooker 1847). A number of important descriptive papers followed this early work on ice algae, revealing their importance in the productivity of polar oceans (Alexander 1974; Burkholder and Mandelli 1965; Meguro et al. 1967). More than a decade ago the work of J. Bunt and colleagues provided preliminary information about the physiological ecology of the ice microflora in Antarctica (Bunt and Lee 1970). During the 1981 field season, our group studied the distribution, production, and strategy for survival in the dark of the sea ice microbial community in McMurdo Sound.

Growth of the sea ice microbial community was observed at nine stations in McMurdo Sound (figure 1). At each station an ice auger was used to collect five ice core samples approximately 1 meter apart from one another. After 17 to 22 days a second set of five samples was taken by removing ice cores from the sites where the first cores had been collected. This repetitive sampling scheme allowed us to determine changes in the standing crop (chlorophyll *a* per square meter) of the ice community as a function of time. At most stations we observed significantly higher standing crops at the second sampling, indicating that net growth and accumulation of the ice community had occurred during the 3- to 4- week period. At one station the crop increased approximately threefold during the sampling interval. One exception was at New Harbor, where the crop was unchanged on the second sampling date. However, late in the season the ice was thinner at this station, indicating that a portion of the under-ice community may have been lost during the intervening period as a result of ice ablation.

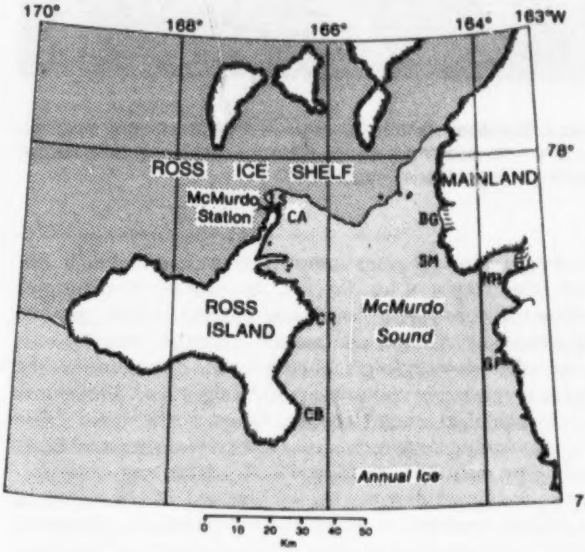

Figure 1. Sample locations for sea ice microbial community studies conducted during 1981 in McMurdo Sound, Ross Sea. Abbreviations: IS, Ross Ice Shelf; CA, Cape Armitage; TR, Turtle Rock; CR, Cape Royds; CB, Cape Bird; GP, Gneiss Point; NH, New Harbor; SM, Strand Moraines; BG, Blue Glacier.

Early in the year the mean standing crop for nine stations was 63.8 ± 40.5 milligrams of chlorophyll *a* per square meter; later it was 129 ± 90 milligrams per square meter. At the later sampling, some of the stations approached the theoretical maximum standing crop of diatoms, 400 milligrams of chlorophyll *a* per square meter, estimated for natural waters by Steemann-Nielsen (1962). This observation is remarkable because the under-ice algal community probably receives less than 1 percent of the surface irradiance. The late-season crop provides an estimate of annual sea ice production of 4.9 grams of carbon per square meter. Such a calculation is reasonable, since production accumulates as the microalgal community is physically entrapped within the ice matrix, reducing losses from grazing and sinking. This is an underestimate of production, because the growing season was not complete at sampling time, and the estimate does not take into account losses due to grazing at the interface of ice and seawater. Also unaccounted for is secondary production by the abundant and diverse ice bacteria described previously (Sullivan and Palmisano 1981).

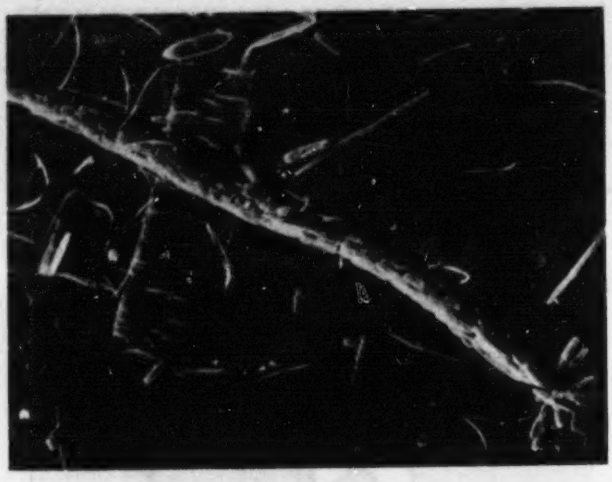

Figure 2. Scanning electron micrograph depicting colony morphology of a tube-dwelling pennate diatom collected at New Harbor sampling station. Magnification, 200X.

Among the nine stations sampled, three had strikingly different assemblages of ice diatoms. At most stations the predominant diatoms were *Amphiprora* species, which grew as long, ribbonlike colonies, and two other colonial diatoms occurring as stellate growth forms. These pennate diatoms represent as much as 86 percent of the observed ice algae at seven stations. A distinctive algal assemblage was found at the New Harbor station, including large numbers of at least two species of tube-dwelling pennate diatoms (figure 2). Tubes as long as 10 centimeters contained dark red-brown pigmented cells that were particularly sensitive to light; their pigmentation changed rapidly from red-brown to green when exposed briefly to more light. The 92-centimeter-thick sea ice at Cape Royds harbored a rich microalgal growth (294 milligrams of chlorophyll *a* per square meter) dominated by a chain-forming, centric diatom identified as *Porosira pseudodenticulatus* (Hustedt) Zhusé. Dense chains of these diatoms penetrated into the ice only a short distance (1–2 centimeters) but hung down into the underlying water column 5 to 10 centimeters. Of the 143 ice cores examined during our 2-year study, only those collected at Cape Royds have shown centric diatoms in greater abundance than pennate diatoms.

Preliminary evidence obtained during our work in 1980 in McMurdo Sound suggested that light was a major factor limiting growth of the sea ice microbial community. In 1981 we found that snow cover on the ice was negatively correlated with chlorophyll *a* per cubic meter. Since snow cover has a strong effect on light penetration (Maykut and Grenfell 1975), the negative correlation indicates the influence of light on the distribution of standing crop in the ice.

In areas of known snow cover near Cape Armitage, scuba divers measured the under-ice irradiance. Irradiance below 148–180 centimeters of ice with 4 centimeters of snow cover ranged from 0.20 to 3.12 microeinsteins per square meter per second at various times of the day, between 26 October and 10 December 1981. The ice algal layer increased during this period from 3.3 to 100 milligrams of chlorophyll *a* per square meter, also reducing the quantity and quality of light penetrating the ice. We also noted the effect of diurnal changes in sun angle on the under-ice light field. At the surface, light declined from 1,500 to 1,300 microeinsteins per square meter per second (a 13-percent decrease), while beneath the ice the change was from 2.90 to 0.48 microeinsteins per square meter per second (an 83-percent decrease). In contrast, Littlepage (1965) concluded from seasonal studies that sun angle has little effect on the under-ice light field.

During the period 26 October to 10 December 1981, the highest under-ice irradiance was less than 1 percent of surface light. The 1 percent light level is conventionally used by biological oceanographers as the compensation intensity for phytoplankton (the irradiance at which photosynthesis is just balanced by respiration, i.e., no net photosynthesis). This provides additional evidence that some antarctic phytoplankton and ice algae are highly adapted to shade (Bunt 1968; Fogg 1977).

Our previous studies (Palmisano and Sullivan in press) suggested that reduced light may be an important environmental cue signaling the oncoming antarctic winter. Darkness may well be the major environmental factor that ice algae must contend with to survive the harsh winter. To examine the response of the sea ice community to darkness, we covered a 100-square-meter quadrat on the sea ice near Cape Armitage with 70 centimeters of snow, thus excluding light from the under-ice community (figure 3). An adjacent, unperturbed quadrat of the same dimensions, with a natural snow cover of 4 centimeters, served as a control. We reasoned that a comparison of these two communities might reveal strategies required of ice algae to survive the polar winter.

Samples for biomass analysis were taken by collecting five ice cores with ice augers on 24 October, 18 November, and 17 December 1981. During this same period, *in situ* incubated experiments were conducted using scuba to measure metabolic rate processes such as ($H^{14}CO_3^-$; carbon-14–sodium bicarbonate) primary productivity (^3H-thymidine; tritiated thymidine), DNA synthesis, and (^{14}C-amino acid; carbon-14–amino acid) heterotrophy. Biomass and metabolic rates were significantly lower in the perturbed quadrat than in the control quadrat. This experi-

Figure 3. Light perturbation experiment on the annual sea ice near Cape Armitage. U.S. Navy snow scoop was used to construct a 100-square-meter quadrat with 70-centimeter snow cover in order to darken the sea ice microbial community at this site; the adjacent control site was left undisturbed with a 4-centimeter natural snow cover.

mental design will be expanded during the 1982–83 field season to determine the factors that influence the growth and development of the sea ice microbial community in McMurdo Sound.

We are grateful to Greta Fryxell for identifying *Porosira pseudodenticulatus*. We thank Sarah McGrath Grossi for reviewing the manuscript and Linda Reppas for typing the manuscript. This research was supported by National Science Foundation grant DPP 79-20802.

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Ice algal communities in the Weddell Sea

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Algae that live within sea ice may be important primary producers and may serve as seed populations for communities in the underlying water column. To study these ice populations and to determine their relationships to pelagic communities, we collected both water and ice samples from the Weddell Sea in January and February 1980. From the samples we have determined chlorophyll *a* biomass and species composition and have correlated our findings with data on the nutrient levels from these environments (Ackley et al. 1980; Foster et al. 1980).

Table 1. Average chlorophyll *a* concentrations and total chlorophyll biomass in the water column and in ice algal communities*

	Chlorophyll *a* concentrations (milligrams per cubic meter)	Total chlorophyll (milligrams per square meter)	Ice thickness (meters)
Water column (upper 50 meters)	0.30	12.2	—
Sea ice			
Newly forming	8.04	0.9	<.26
First year	1.25	1.6	1.3
Multiyear	1.00	4.8	4.2

*Chlorophyll biomass was integrated over the upper 50 meters in the water column.

Our samples indicate that algal concentrations are higher in sea ice than in the water column. However, since ice is limited to a relatively thin surface layer, total standing crop in the water column is usually greater than in sea ice (table 1). In newly formed ice, high chlorophyll concentrations that could not be explained by *in situ* growth led us to hypothesize that algae can be physically harvested during frazil ice formation (Ackley 1982; Buck and Garrison 1982; Garrison and Buck 1982).

We have used nutrient concentrations and salinity as indicators of biological activity within ice. The pattern of reactive silicate distribution was characteristic of that of other nutrients: concentrations were high in surface waters and markedly reduced in ice samples (figure 1). If silicate functions as a conservative salt, its concentration can be predicted by salinity, and salinity decreases in ice as a result of brine rejection. Deviations from the silicate value predicted by salinity (i.e., residual concentrations) most likely indicate biological uptake or regeneration. We tested for such biological processes by comparing residual nutrient concentrations with algal biomass (figure 2).

In newly forming ice, residual nutrient concentrations were small and were not correlated with algal biomass. Such results are consistent with the hypothesis that these populations are mechanically harvested during ice formation. In ice floes, on the other hand, observed concentrations of reactive silicate were considerably lower than predicted, indicating uptake by diatom populations; however, algal biomass was unrelated to residual concentrations, and chlorophyll concentrations were less than would be expected if these residual nutrients had been incorporated into diatom populations. Siliceous heterotrophs were not sufficiently abundant to explain the low silicate concentrations; furthermore, there were relatively high concentrations of am-

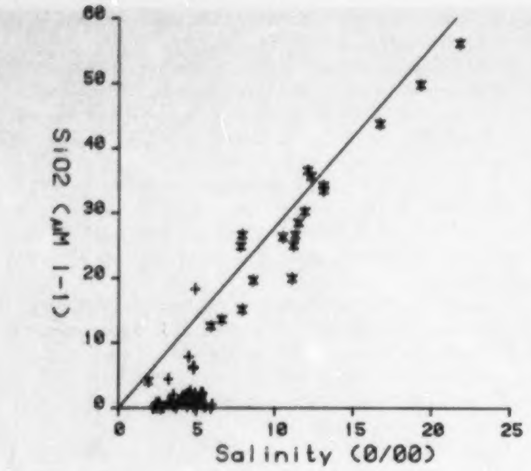

Figure 1. The relationship between reactive silicate (SiO_2) and salinity in ice samples. The solid line is the SiO_2/salinity relationship in surface water samples at ice edge stations (i.e., 93.2 micromoles of SiO_2 per liter/33.9 ‰).

Table 2. Abundance of major taxa of microplankton (in cells per milliliter) in the water column and in ice algal communities

Group	Station Pi02[a] Water	Station Pi02[a] New ice	Core 51G4[b] (first-year floe)
Phaeocystis	3,641	41,644	1,825[c]
Diatoms	746	38,613	84,000[c]
Archaeomonads	12	835	+[d]

[a] Station Pi02: 39°26′W 70°16′S.

[b] Core 51G4: 43°43′W 73°24′S.

[c] Maximum number in core.

[d] Present but not enumerated.

monium in floe ice. These observations suggest decomposition of diatoms within the older ice. Thus, algae in young ice and floe ice are in different stages: the early stage of physical accumulation and the later stage of decomposition following algal growth, respectively.

A preliminary analysis of the composition of the algae in the water and ice samples showed that *Phaeocystis* was the dominant alga in many water column and newly forming ice samples, whereas diatoms predominated in ice floes (table 2). Diatom assemblages were very similar in water and newly forming ice, and the same species occurred in the water column and in ice floes (see table 3). A few diatom resting stages were observed in the water column and in newly forming ice, and Archaeomonad cysts were abundant in both ice and water (Mitchell and Silver 1982).

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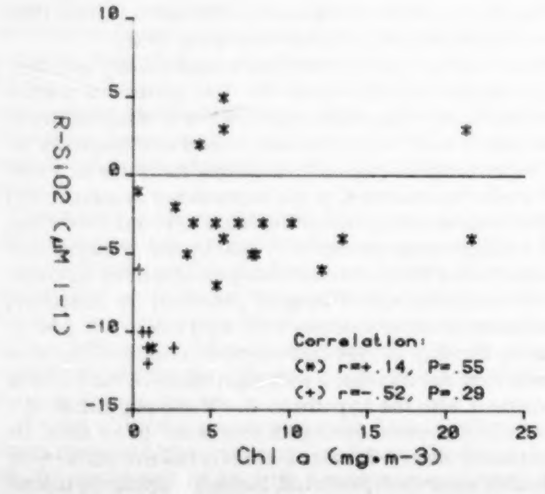

Figure 2. Residual silicate concentrations (R-SiO_2; in micromoles per liter) vs. chlorophyll *a* (in milligrams per cubic meter). Residual concentration = observed concentration − concentration predicted by the SiO_2/salinity relationship shown in figure 1. * = newly forming ice samples; + = ice core samples from first-year and multiyear ice floes.

Table 3. Relative abundance in diatom species in newly forming sea ice compared with adjacent surface water sample and the present (+) or absence (−) of these species in ice core samples

Species	New ice (%)	Adjacent surface waters (%)	Ice core samples
Nitzschia cylindrus	56	30	+
N. closterium	18	5	+
N. curta	7	45	+
N. kerguelensis	3	0	−
N. turdiguloides	3	3	+
N. angulata	2	1	−
N. subcurvata	2	1	+
N. pseudonana	0	1	−
N. sublineata	0	1	−
N. ritscheri	0	1	−
N. neglectum	0	1	+
Tropidoneis glacialis	4	1	−
T. fusiformis	2	1	−
T. gaussii	0	1	−
T. belgicae	0	1	−
Amphiprora kjellmanii	0	1	+
Chaetoceros simplex	1	4	+
C. dichaeta	2	2	+
C. criophilum	0	1	+
Rhizosolenia inermis	2	1	+
Odontella weissfolgii (resting cells)	0	1	+
Dactyliosolen antarcticus	0	2	−

made available by T. D. Foster, and J. G. Mitchell helped on the sampling cruise. Much of this study is part of a collaborative effort with S. F. Ackley, and we thank him for his continuing support and involvement.

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Biology and ecology of shallow-water rhizopodia in McMurdo Sound

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The principal objective of this investigation was to study the distribution, ecology, and physiology of shallow-water benthic foraminifera in McMurdo Sound. Study sites were chosen to include a wide range of the environmental conditions known to exist in the sound. The shallow-water benthos of the eastern and western sides of McMurdo Sound differ in diversity, abundance, and species composition (Dayton and Oliver 1977). These differences in the benthic communities probably result from the effects of patterns of water currents and the persistence of ice cover on organic input to those areas (DeLaca, Lipps, and Hessler 1980; Hodson et al. 1981; Holm-Hansen et al. 1977). Recent findings (Stockton in preparation) have revealed a spectrum of environments that differ in organic input and substrate composition on the western side of the Sound.

In mid-January 1981, the participants of this project began a 2-year investigation. The first summer's work consisted of a 3-week survey of foraminiferal distribution and the initiation of laboratory investigations at the Eklund Biological Center at McMurdo Station for continued studies during the winter of 1981. In latter studies, winter-over personnel monitored environmental parameters and the population dynamics (standing stocks and biomasses) of *Gromia oviformis* (Testacida) and associated foraminifera in the immediate vicinity of the salt water intake pipe at Cape Armitage. These investigations provided information on small-scale distributions of benthic rhizopodia and yielded interesting correlations with substrate type and the proximity of various larger organisms in the soft-bottom communities in that area.

The second year's investigations began in early October 1981 with the reoccupation of study sites on the western side of the sound. A field camp was established at Explorers Cove, New Harbor. Much of our effort focused on this camp on the sea ice and on the marine sediments under it. We used 10 diving access holes in the vicinity of Wales Stream to extend our knowledge of this area, and we studied two widely separated areas on the northern margins of Explorers Cove. A total of 350 man dives were made. We extended our knowledge of western McMurdo Sound through aerial and diving reconnaissance at several sites from Miers Valley, near the Koettlitz Glacier, to Discovery Bluff in Granite Harbor (a distance of 120 kilometers).

Studies have demonstrated marked differences between the rhizopod species in the eastern side of the sound (Cape Armitage) and those in the western side (Explorers Cove). Although these two regions have some of the same species, within comparable substrates, Explorers Cove has a higher species diversity and a lower total abundance and biomass than has the more productive Cape Armitage. Several species of the New Harbor assemblages have extremely wide bathymetric ranges (*Bathysiphon filiformis* and *Rhabdammina abyssorum;* see Milam and Anderson 1981), and several possess arborescent morphologies or erect habits (e.g., *Notodendrodes antarctikos;* DeLaca et al. 1980). Four large (greater than 0.5 millimeter) species were found in the western sound that have not been described previously. Comparisons of rhizopod species representing a spectrum of morphologies and behaviors were undertaken in field studies at the New Harbor camp, at the Eklund Biological Center, and later at Scripps Institution of Oceanography. Included in the comparison were the foraminifera *Notodendrodes antarctikos*, Astrammina rara, Astrorhiza c.f. *limicola*, *Pyrgo depressa*, *Psammetta globosa* (Xenophyophorida), and *G. oviformis* (Testacida). These studies found quantitative and qualitative differences in physiological tolerance, ability to take up and metabolize dissolved organic substances, and ability to consume marine bacteria.

Field operations were concluded 9 February. For a second year, winter-over personnel continued year-long studies, including monitoring of chlorophylls, phaeopigments, and particulate organic carbon in the sediments; analyses of change in total meio- and macrofaunal composition and biomass; and analyses of changes in abundance, biomass, and chemical composition of selected rhizopod species in soft substrates adjacent to McMurdo Station.

Although most of these studies focused on benthic rhizopods, especially foraminifera, a variety of peripheral investigations related to this theme also were undertaken. These included analysis of various sources of organic materials potentially affecting the energetics of the near-shore benthos; marine sedimentation; and submarine glaciology. Reports of these studies are being prepared for publication.

Participants in this project have been: first season—T. E. DeLaca, W. L. Stockton, G. P. Shreve, P. A. Berkman, and D. S. Marks; second season—Delaca, Stockton, L. S. Mullineaux, M. L. Tracey, R. B. Sharman, T. L. Roberts, and G. T. Williams. This work was supported by National Science Foundation grant DPP 80-03432.

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Phytoplankton cultures and collections around South Georgia

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Cooperation with the British Antarctic Survey early in the austral summer of 1981–82 yielded valuable phytoplankton samples from the vicinity of South Georgia. These samples comprise the best collections since the days of the *Discovery* cruises. During the first leg of RRV *John H. Biscoe* cruise 3, 17 November–19 December 1981, an acoustic survey for krill (*Euphausia superba*) was conducted in a tight grid around South Georgia. Bottom topography and krill patches were mapped, and a total of 64 phytoplankton stations (figure 1) were taken. At each station, discrete samples were taken from Niskin bottles (at four depths) to be used in making quantitative estimates, by microscopical examination, of phytoplankton species present at selected stations. In addition, at each station 35-micrometer-mesh vertical net hauls were made from a depth of 200 meters, where possible, for concentration of less common, larger species, taxonomic study of abundant species, and study of resting spore formation. Preliminary analysis of net hauls has shown dominance of *Thalassiosira* and the *Fragilariopsis* group of *Nitzschia*. Abundant species include: *Chaetoceros* species, *Corethron criophilum* Castracane, *Eucampia balaustium* Castracane *Nitzschia cylindrus* (Grunow) Hasle, *N. kerguelensis* (O'Meara) Hasle, *N. sublineata* Hasle, *Porosira glacialis* (Grunow) Jørgensen, *Thalassiosira gravida* Cleve, *T. lentiginosa* (Janisch) G. Fryxell, and *T. scotia* G. Fryxell et Hoban.

The second leg of the cruise, after 25 December, covered a much smaller area, around 54°S 36°W. An intensive 22-day study was made of a single krill patch, including acoustic runs and measurements of chlorophyll *a* and primary productivity.

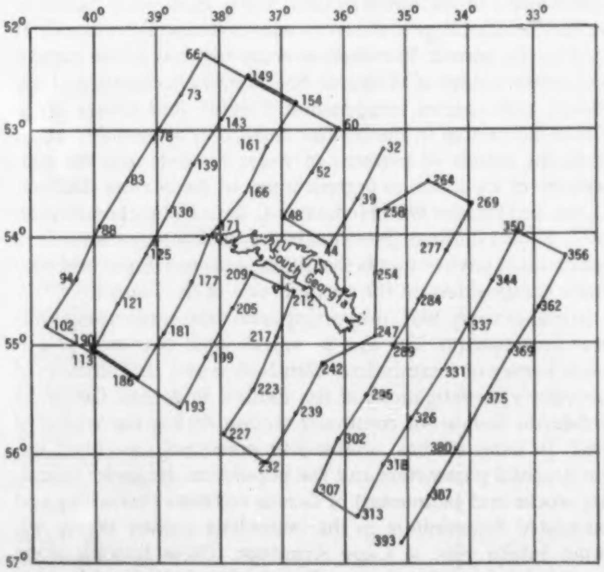

Figure 1. Cruise track of RRV *John H. Biscoe*, cruise 3, leg 1, 17 November–19 December 1981, British Antarctic Survey, Offshore Biological Program.

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A total of 15 phytoplankton stations were taken during this leg, under grey skies and a steady wind, following the same procedure as that carried out on the first leg.

Living material was brought to Texas A&M University by Tracy A. Villareal, who replaced one of us (JRJ) for health reasons on the second leg of the cruise. *Corethron criophilum*, supposedly avoided by krill as food, has been established in culture.

Thalassiosira scotia Fryxell et Hoban was observed in high numbers at stations 209 and 212, near the southern coast of South Georgia (figure 1). This species was in the process of resting spore formation, providing an excellent opportunity for the study of the external morphology of the spores (Johansen, Doucette, and Fryxell in preparation). Resting spores were found to be heterovalvate. The first valve formed is flat, heavily silicified, and coarser than the vegetative valve, and it has fewer central strutted processes than the vegetative valve (7–12 compared with 10–25). The second resting spore valve formed has still fewer central processes (1–4), is arched, and has densely arranged, occluded processes that are flared at the tips. Absent are marginal striae with "shoes," villi surrounding the areolae, and veruculose surface texture.

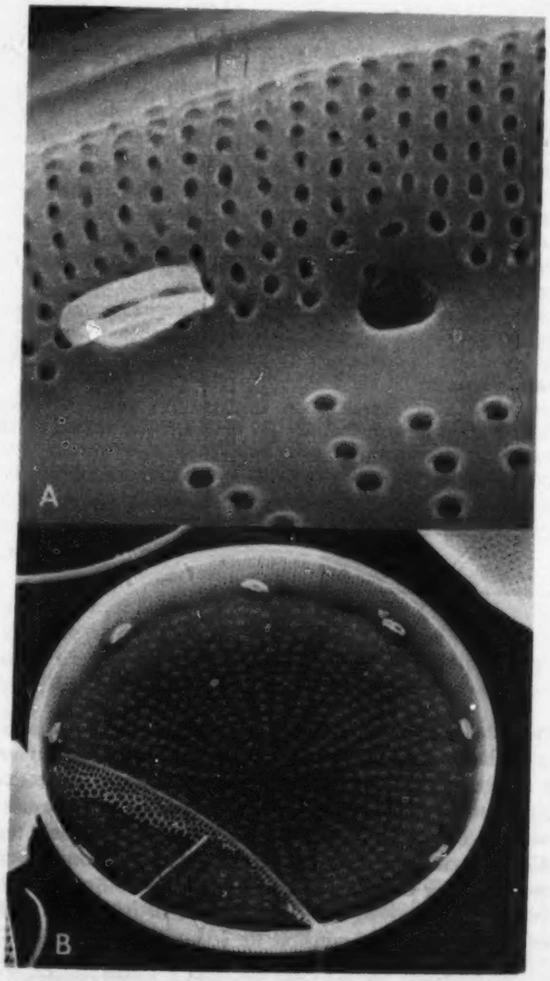

Figure 2. *Actinocyclus actinochilus*, scanning micrographs of biological inside of valve. A: Labiate process by pseudonodulus that places it in the genus *Actinocyclus* but is a variable feature (collected by T. M. Whitaker, British Antarctic Survey, diving from small iceberg shelf off Signe Island); B: Distinctive areola pattern with many labiate processes on the margin and a pseudonodulus at the 3 o'clock position on the valve (collected by M. A. Hoban, *Islas Orcadas* cruise 17/78). Magnification, 1,800X.

Resting spores of *T. scotia* closely resemble those of *T. antarctica var. antarctica*, and the vegetative frustules of the two taxa also are very similar, especially their process patterns. *T. scotia* generally is more heavily silicified and coarser in areolation, and has larger and more abundant occluded processes. The observation of a few valves resembling *T. scotia* in a clonal culture of *T. antarctica* leads us to suspect that these taxa may be conspecific. The bimodal distribution of morphological characters, with few intergradations, indicates that the presence of one form to the exclusion of the other may have ecological, if not genetic, significance.

We have continued to study *Thalassiosira antarctica*, which occurs in both polar seas but not in the waters in between. Morphological and ultrastructural differences between vegetative stages of northern and southern populations are negligible. Major morphological differences between resting spores of the two clones have been reported previously (Fryxell, Villareal, and Doucette 1981). Ultrastructural studies of the resting spores of both varieties show that, during resting spore formation, a large number of mitochondria are discarded into the residual body associated with the rudimentary valve. Occasionally, chloroplasts and lipids are lost. The mitochondria present in resting spores are larger than those of vegetative cells, indicating that mitochondrial fusion might be taking place. An increase in lipid reserves also occurs in conjunction with resting spore formation. In general, the spore of *T. antarctica* var. *antarctica* has more, though smaller, lipid droplets than var. *Borealis* (Doucette 1982).

Autecological studies of *T. antarctica* and *Porosira glacialis* revealed that "cold water forms" were present (Villareal 1981). At temperatures near that of melting sea ice, the external occluded processes were completely missing from valves of *T. antarctica*, and the labiate process tube disappeared from *P. glacialis*. The external openings of the areolae (foramina) were constricted, explaining some of the morphological differences noted near ice.

Villareal (1981) concluded that the bipolar distribution of *T. antarctica* has its origin in the transport of resting spores from one polar region to the other. The probable direction of transport is south to north; on the basis of the present current regime and the apparent centers of radiation of the species involved, the Atlantic Ocean is considered the most likely area for the transport to occur. That bipolar distribution is a transient event geologically is supported by the divergent evolution of the disjunct populations we have been studying.

The genus *Thalassiosira* Cleve is well represented in antarctic waters. It is known to dominate the flora in blooms at times. A key of better known species is being prepared (Johansen and Fryxell in preparation).

Actinocyclus Ehrenberg also is well represented in antarctic waters. Cooperative work with H. J. Semina, U.S.S.R., resulted in the description of a new species, a nanoplanktonic taxon (Fryxell and Semina 1981). *A. actinochilus* (Ehrenberg) Simonsen [= *Charcotia actinochilus* Ehrenberg] is also abundant in antarctic waters and in ice flora (figure 2). It has been isolated from living samples from McMurdo Sound, which were kindly provided by

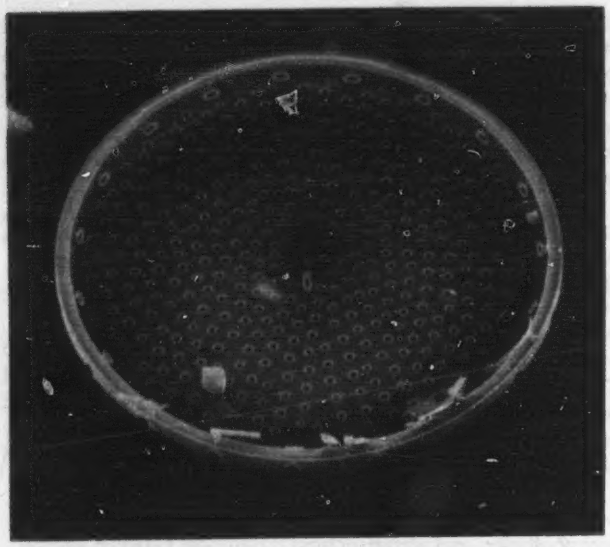

Figure 3. "*Coscinodiscus*" *tabularis*, with *Actinocyclus*-type processes around the margin plus a central labiate process (collected by Dean A. Stockwell, *Marion Dufresne*, Station 9). Magnification, 1,600X.

C. W. Sullivan. Samples from recent cruises, as well as living material, have been used in a discussion of the genus (Villareal and Fryxell in press). Closely related to *Actinocyclus* is one group of species now considered in the genus *Coscinodiscus*. Especially common in the material gathered by the *Marion Dufresne* (southern Indian Ocean, 1976) was *Coscinodiscus tabularis* Grunow (figure 3); its study is a significant part of the work now under way to give generic standing to a half-dozen or so oceanic species (Fryxell in preparation).

We express gratitude to those of the British Antarctic Survey who took samples for us on the first leg of the cruise, especially to Terence M. Whitaker and R. B. Heywood. We also thank T. Phillip Watkins of Texas A&M University for isolations of clonal cultures. This work has been supported in part by National Science Foundation grants DPP 76-80738, DPP 78-23463, DPP 80-20381, and DEB 79-23159.

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Echinoderm biology and general benthic collecting along the Antarctic Peninsula

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From February to April 1982, we continued field and laboratory studies of the diets, feeding behavior, morphology of feeding structures, and general benthic ecology of asterozoan echinoderms (sea stars and brittle stars) along the Antarctic Peninsula (Dearborn, Edwards, and Fratt 1981). The field team included a crustacean specialist (L. Watling). Gordon Hendler, supervisor for benthic invertebrates at the Smithsonian Oceanographic Sorting Center (SOSC), participated in R/V *Hero* cruise 82-4 and was responsible for some laboratory studies of echinoderm behavior and for collecting, sorting, and preserving benthic invertebrates other than asterozoan echinoderms for systematic biologists assisted by SOSC.

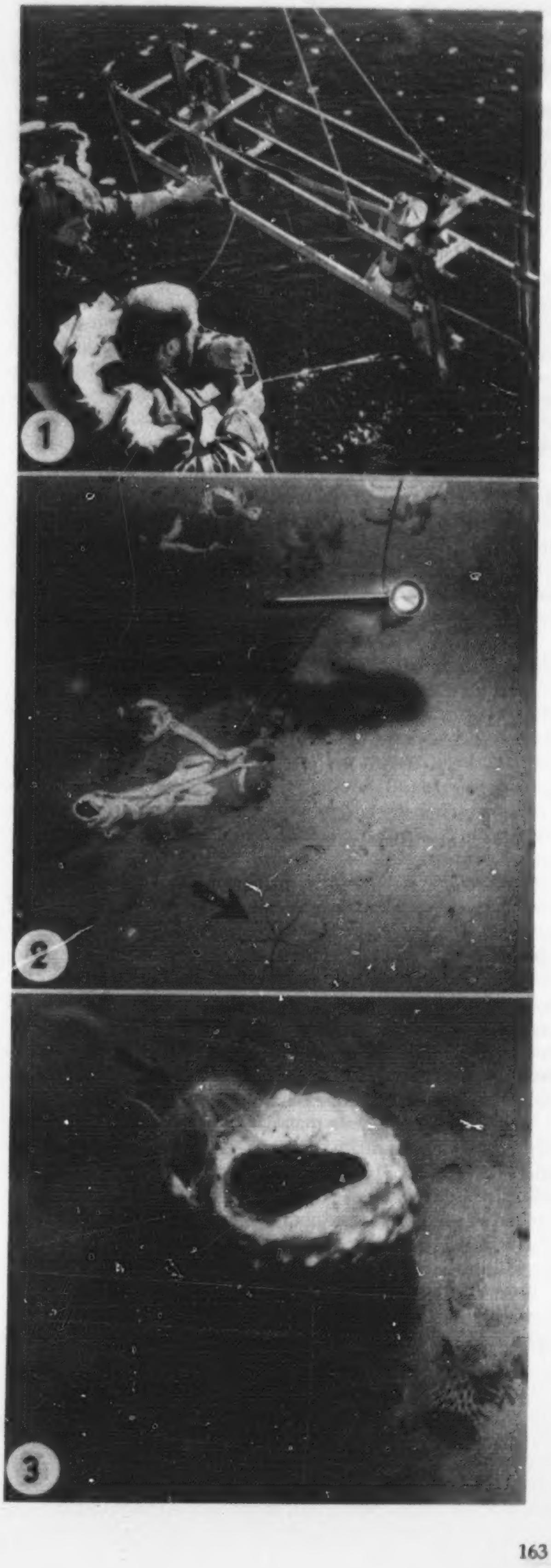
The general purpose of our continuing research is to provide detailed information on the foods and feeding ecology of dominant asteroid and ophiuroid echinoderms found on the antarctic shelf. Qualitative and quantitative determinations of the extent of direct or indirect feeding of these echinoderms on krill and other zooplanktonic or benthic prey and derived detritus provide a basis for evaluating the role of these abundant predators and scavengers in overall energy flow between benthic and planktonic communities. The ecological data obtained will be critical in formulating a realistic model of the trophic interactions of benthic invertebrates, plankton, and fishes developed for the antarctic marine ecosystem.

R/V Hero cruise 82-3. D. Fratt participated in R/V *Hero* cruise 82-3, which left Ushuaia, Argentina, on 29 January 1982. On the way to Palmer Station, on 2 February, several otter trawls were made at Low Island in the South Shetlands to obtain demersal fishes for Audrey E. V. Haschemeyer (Hunter College). These collections included sufficient numbers of the brittle star *Ophiurolepis gelida* for analyses of stomach contents and morphological studies using scanning electron microscopy. Trawls made on 5 and 6 February in cooperation with Robert Y. George (University of North Carolina at Wilmington) also provided echinoderm material for us, including specimens of the large sea star *Labidiaster annulatus* and the brittle star *Ophionotus victoriae*, both key species in our ecological studies. Later cooperative efforts of D. Fratt and scuba divers Langdon Quetin (University of California at Santa Barbara) and Flip Nicklin (National Geographic Society) provided specimens of the unusual asteriid sea star *Granaster nutrix* from near Palmer Station. D. Fratt and Richard B. Williams (National Science Foundation) used zodiacs to obtain additional *Granaster* near Litchfield Island.

In the Palmer Station laboratory, a flow-through aquarium was used for observation of the feeding strategies of *Ophionotus victoriae*. Changes in feeding postures with variations in current velocity were noted. Methods of capture and handling of food from the water column and substrate were studied by offering krill, bivalves, polychaetes, and carmine particles to starved specimens.

Qualitative observations on the feeding of *Labidiaster annulatus* also were made. With the help of Flip Nicklin, close-up photographs were taken of this sea star feeding on live krill. These sequences show the capture of krill by pedicellariae and subsequent manipulation of the prey by podia and arm surfaces prior to ingestion.

R/V Hero cruise 82-4. J. Dearborn, L. Watling, K. Edwards, and G. Hendler participated in R/V *Hero* cruise 82-4, which left Punta Arenas, Chile, on 8 March 1982. D. Fratt joined the group at Palmer Station on 14 March, and all personnel returned to Punta Arenas on 9 April.



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Underwater camera operations and results. (1) Authors Fratt (left) and Edwards lowering the Benthos, Inc., model 371 underwater camera and model 381 utility flash, 23 March 1982, west of Vladivia Point, east side of Gerlache Strait (photo by J. H. Dearborn). (2) Sea floor at 52 meters depth in Arthur Harbor, between Palmer Station and Torgersen Island. A deep-sea compass with attached vane indicates direction of bottom current. Several specimens of the large nemertean *Parborlasia corrugatus* (left center and top) and an unidentified ophiuroid (arrow) are visible (photo taken 28 March 1982). (3) A large, hexactinellid sponge on the bottom off Prospect Point, 66°05.0'S 65°20.9'W, at 85 meters depth. Several specimens of the comatulid crinoid *Promachocrinus kerguelensis* (arrow) cling to the sponge. The sponge osculum has a maximum diameter of about 25 centimeters (photo taken 17 March 1981).

Locations for sampling benthic invertebrates extended from the northern end of Adelaide Island in the south to King George Island (South Shetlands) in the north, in depths of 33 to 730 meters. A total of 38 trawl or grab stations and 13 underwater camera stations were made. Sixteen rolls of black-and-white film and eight rolls of color film were taken at depth ranging from 33 to 172 meters. These photgraphs will provide data on the nature of sediments, types and distribution of macroinvertebrates, and orientation of echinoderms in relation to bottom currents (see figure, page 163).

A total of 193 echinoderm tissue samples were fixed in a glutaraldehyde/formalin solution for scanning electron microscopy. These samples will be used for detailed morphological studies of six species of sea stars, nine species of brittle stars, and at least five species of crinoids. More than 130 specimens of seven species of sea stars were examined for gut content and stomach fullness. Approximately 1,000 specimens of *Ophionotus victoriae* were obtained from three sites for analyses of stomach contents by size of animal, location, and season.

Forty samples of environmental sediments also were obtained for comparison with sediment from the stomachs of *O. victoriae* taken in the same grabs. Such a comparison should provide information on particle size selectivity, sediment handling and breakdown by invertebrate deposit-feeders, and the nature and extent of sediment organic content utilized by these deposit-feeders.

The collection of benthic invertebrates other than echinoderms centered on obtaining amphipods for taxonomic studies and examining the associated fauna of selected sponges. Many species of amphipods were obtained; those of particular interest represent the families Acanthonotozomatidae and Paramphithoidae. Within the latter, several species of the genus *Epimeria* were found. About 15 species of amphipods larger than 1 centimeter in body length were photographed to record color patterns; in *Epimeria*, these patterns readily separate the closely related species.

Five sponge species were examined for associated fauna. Each sponge was isolated immediately from the general trawl contents. The small animals were extracted from the sponges, washed over a 150-micrometer screen, and sorted from the debris under a dissecting microscope. Many species, chiefly ostracods, isopods, and amphipods, as well as many small polychaetes, gastropods, brittle stars, and sea stars, were obtained. A number of groups usually found in low numbers in sediments, such as sebid and pagetinid amphipods and munnid isopods, were especially abundant in the sponges.

Remaining invertebrate material from trawls and grabs was sorted, and representative specimens narcotized, preserved, and prepared for shipment to the SOSC largely through the efforts of G. Hendler. Approximately four 55-gallon drums of preserved specimens were obtained for the national collections. This material will be distributed to various taxonomic specialists by the SOSC.

Several laboratory experiments were conducted at Palmer Station by G. Hendler and D. Fratt. The rate of digestion of the ophiuroid *Ophionotus victoriae* was estimated using specimens dredged from 50–150 meters and acclimated to the running seawater aquaria at Palmer. The ophiuroids were starved prior to experiments. Series of animals were offered blotted, weighed pieces of *Euphausia* sp. abdomens as food. Ophiuroids that ingested food within 5 minutes were held in running seawater for periods of 1 to 30 hours and then dissected, and the food remaining in their stomachs was removed, dried, and weighed. The weight of material digested during the experimental interval was determined by subtracting the dry weight of undigested food from the calculated dry weight of the ingested piece of *Euphausia* tissue.

The experimental protocol was identical to that previously used (Hendler in press) to determine the digestion rate of the temperate zone ophiuroid *Ophioderma brevispinum* at Woods Hole, Massachusetts. Preliminary calculations for one experiment show that *Ophionotus victoriae* that ingested 15.80-milligrams (mean dry weight) portions of *Euphausia* digested tissue at a rate of 0.63 milligrams per hour. In a second experiment, smaller *Ophionotus* that ingested larger (31.80 milligram) pieces of *Euphausia* digested tissue at 0.76 milligrams per hour. These experiments were carried out at temperatures of from −.05° to 1.0°C. At a temperature of 20.6°C, the temperature zone species *Ophioderma brevispinum* of roughly the same size as *Ophionotus victoriae* digested 16.3-milligram pieces of the shrimp Palaemonetes vulgaris at a rate of 1.01 milligrams per hour.

Additional calculations and comparisons are necessary to interpret the results, but important implications for the ecology and physiology of *Ophionotus victoriae* are already apparent. Interestingly, this antarctic ophiuroid is capable of digesting food at a rate similar to that of a temperate zone ophiuroid despite a 20°C difference in the ambient water temperature of the two species.

Rate processes of ophiuroids were examined by timing the "righting reflex" of various specimens of several antarctic species at ambient temperatures. In addition, more than 30 species of antarctic echinoderms were tested for their ability to luminesce. At least three holothuroid species and four species of ophiuroids examined were capable of luminescence.

This research was supported by National Science Foundation grants DPP 79-21537 to John H. Dearborn and DPP 74-13988 to the Smithsonian Oceanographic Sorting Center, and by a grant from the Fluid Research Fund of the Secretary, Smithsonian Institution, to Gordon Hendler. We are indebted to Captain Pieter Lenie and the crew of the *Hero* for their field assistance.

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Procedures for *in situ* observations of krill schools in the southern ocean

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Only a few observations of euphausiids are reported in the literature (Fenwick 1978; Kils 1979; Pavlov 1969; Ragulin 1969). In this article I describe the procedures we used to locate and observe schools of the antarctic krill, *Euphausia superba*, under water with scuba in the austral summer of 1982.

On three cruises of the R/V *Hero* in January and February 1982, divers were deployed in the Gerlache Straits, the Bransfield Straits, Charlotte Bay, the Drake Passage outside Livingston Island, and near Elephant Island. The *Hero* found numerous aggregations of *E. superba*, usually by echo sounder but also by watching for krill predators—primarily humpback whales, *Megaptera novaeangliae*, and Wilson's storm petrel, *Oceanites oceanicus*. These aggregations were sampled with a midwater trawl, but most were too deep for direct observations by divers, who were limited to 20 meters depth.

Our research team of five divers made 12 separate dives in deep-water locations that appeared promising for krill observations. We sighted krill on only six of these dives. Of the six, three took place between 1600 and 1700, and one was at midnight; our use of lights for these dives clearly altered the krill's behavior. Krill were sighted on a fifth dive, made at 1400 in the Drake Passage near Livingston Island, but they were most abundant below 20 meters and were difficult to see from above. The most productive dive was in Crocker Passage on 17 February between 0500 and 0730. The water was exceptionally clear, with 30 meters horizontal visibility, the sea was flat, and the weather was clear and windless. Immense schools of *E. superba* surrounded the *Hero* in the surface waters, and we made most of our behavioral observations on this occasion.

Both our research team and the *Hero's* crew kept constant watch for krill aggregations. Divers were on 24-hour standby, with dry suit diving equipment fully readied. Using dry suits of noncompressible material, with large passive exhaust valves for buoyancy control, and underwear of thick polypropylene for insulation, divers could stay in water of 0°–1°C for 2½ hours. When krill were located, a surface drogue was thrown from the ship to mark the site. Divers left the *Hero* in a rubber boat and were under water within 20–30 minutes. Speed was important both because the krill schools moved horizontally quite rapidly and because research time aboard the *Hero* was shared by four research groups.

We used bluewater diving techniques modified after Hamner (1975, 1979). Divers entered the water from a 16-foot (4.7-meter) rubber boat and swam on the surface along a slack buoyant line tethered from the boat to a float 20 meters away. A vertical, 30-meter down-line, weighted with a 2-kilogram weight and knotted at 10 and 20 meters, was tied to the float. Each research diver attached a 20-meter safety line to the down-line, as described by Hamner (1975). One safety diver watched depth limits and diving time and kept the research divers' safety lines untangled. If the divers did not see a school of krill or if the school moved away, the divers would swim horizontally, towing the down-line and the surface float with their safety lines. The boat operator would follow the tethered float, keeping slack in the line to avoid straining the lines under water. In this way the divers maintained continuous line contact with their surface support, of vital importance in open-ocean diving. Safety precautions are even more important in Antarctica because of the intense cold, rapid weather changes, and the necessity of immediate rescue in an emergency.

We could approach within 1 meter of schooling krill by swimming slowly toward the school from the side. Approach from above caused avoidance in response to the diver's silhouette; from below, rising exhaust bubbles from the diver's regulator would scatter the school. At distances of 1 to 2 meters divers can readily collect data on density, orientation, swimming speed, size and shape of schools, interactions of individuals within the schools, feeding, molting, excretion, and reaction to predators. *In situ* information of this type is critical to an understanding of the biology of *E. superba*.

The research diving team—W. M. Hamner, R. W. Gilmer, P. P. Hamner, C. P. Nicklin, and S. Strand—operated from Palmer Station and the R/V *Hero* from December 1981 to March 1982. This research was supported by National Science Foundation grant DPP 80-23851.

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Euphausia superba: Fecundity and physiological ecology of its eggs and larvae

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During USARP 82 we measured spawning frequency in schools of krill near Elephant Island and the South Shetland Islands, Antarctic Peninsula, on two cruises of the R/V *Hero*. At Palmer Station we began to gather the data necessary to determine the depth at which eggs hatch and the rate at which energy reserves in early nonfeeding stages are depleted.

There are a number of conflicting views about the spawning behavior of *Euphausia superba*. El-Sayed and McWhinnie (1979) support the view that krill spawn possibly twice a year for a period of 2 years; they also suggest that each brood contains 1,000–2,000 eggs. We used a modification of the method developed by Ross, Daly, and English (1982) to measure the spawning frequency of live *Euphausia superba* on board the *Hero*. The inverse of the daily spawning frequency is the interval between broods. We calculated the brood interval for four schools of krill sampled near Elephant Island in January and for three schools found on the outside of the South Shetland Islands in February (table 1). The average brood intervals calculated for days 2 and 3 and for days 2, 3, and 4 were about the same. For all but school 8, the average brood interval for days 2, 3, and 4 was 5–7 days, in both January and February. We are not sure whether the longer brood interval of 11.4 days for school 8 was significantly longer or within the range of variability, and we intend to investigate this question during the 1982–83 season. Brood size varied greatly and was not closely linked to size of the female. It appeared that each female released 1,000 to 6,000 eggs with each brood; the median brood size (from the data analyzed thus far) was 2,000 eggs.

Table 1. Brood interval (in days) of schools of *Euphausia superba* in the Antarctic Peninsula, USARP 82

Location/ School number	Date	Average brood interval Days 2–3	Average brood interval Days 2–4
Elephant Island			
4	8 Jan	6.0	6.5
6	9 Jan	10.7	7.2
8	9 Jan	11.4	—[a]
14	12 Jan	7.4	6.4
South Shetland Islands			
23	13 Feb	8.0	7.1
25	13 Feb	4.9	5.6
26	14 Feb	5.2	—[a]

[a] Females were observed for only 3 days, so the average brood interval for days 2, 3, and 4 could not be calculated.

Although we were not able to determine spawning frequency in December and March, we did find reproducing females in late December, indicating that the spawning season of *Euphausia superba* lasts at least 2 months. Assuming a brood interval of 6 days, a spawning season of 2 months, and a brood size of 2,000 eggs, a single *Euphausia superba* will release about 20,000 eggs in a season. This estimate of the fecundity of individual females is 5–10 times greater than previous estimates made by investigators who worked primarily with frozen or preserved animals.

We used eggs released from female krill brought back to Palmer Station to measure the sinking rate of the eggs during their development and to determine hatching and developmental times of the eggs and early larvae. The average sinking rate of eggs from an individual female varied with age or developmental stage of the egg (figure 1). For the first 24 hours the sinking rate was about 195 meters per day; between 36 and 72 hours after release the sinking rate decreased to a minimum of 95 meters per day and then increased again prior to hatching. The individual observations of sinking rates were not always distributed normally. After the blastula stage (24–36 hours) the distribution was either skewed or bimodal; at limb bud stage (78–123 hours) the point distribution was again normal. Using rough averages of egg sinking rates calculated every 24 hours for 135 hours, we estimated that with no, or low, vertical water velocities the eggs should hatch above 700 meters.

Despite inadequate temperature control (0.5°C ± 0.5°C), eggs in about 44 percent of the broods released in February and

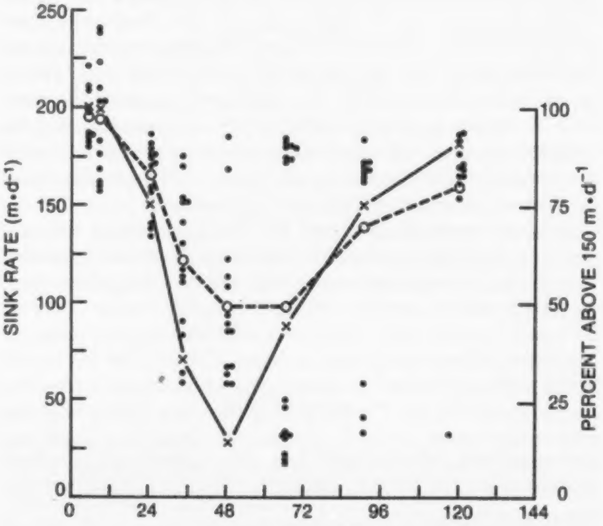

Figure 1. Sinking rates (in meters per day) of individual eggs from a single brood of *Euphausia superba*, from release to hatching, at a temperature of 2.0°C and a salinity of 36.2‰ (equivalent to a water density of 1.029 grams per cubic centimeter). Each sinking rate measurement is represented by a closed circle; the average sinking rate at each age is represented by an open circle; and the average rates are connected by a dotted line. The percentage of measurements above 150 meters per day ($m \cdot d^{-1}$) at each age (x) is on the right y-axis; the points are connected by a solid line.

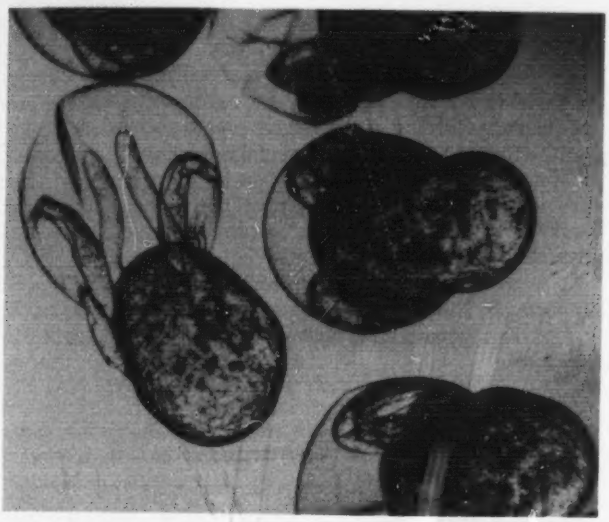

Figure 2. Nauplii hatching from eggs released by *Euphausia superba* at Palmer Station during USARP 82. (Photo by L. B. Quetin)

Table 2. Developmental times (in days) for larvae of *Euphausia superba*

	Investigators		
Stage	McWhinnie & Denys (1978)	Witek et al. (1980)	Present study (USARP 82)
Egg to nauplius I	3–4	N.D.[a]	5–6
Egg to nauplius II	7–8	N.D.	8–10
Egg to metanauplius	10–18	N.D.	15–18
Egg to calyptopis I	N.D.	30	21–25
Egg to calyptopis II	N.D.	45, 50, 60[b]	32–37

[a] N.D. = no data.

[b] Field estimates based on first, middle, and last time of spawning to first, middle, and last appearance of calyptopis II in the plankton.

March went on to hatch (figure 2). Usually, either all the eggs hatched or none hatched. We found developmental times for the naupliar stages comparable to those that McWhinnie and Denys (1978) found. Laboratory estimates of developmental times for the calyptopis stages, however, appear to be shorter than field estimates (Witek, Koronkiewicz, and Soszka 1980) (table 2). Newly hatched larvae must reach the surface in 21–25 days, if surface food sources are vital to their development at the first feeding stage (calyptopis 1).

We thank Captain P. Lenie, the crew of the R/V *Hero*, and the support personnel at Palmer Station for their outstanding support of our research efforts. This research was supported by National Science Foundation grant DPP 80-20739.

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Diatoms from brittle star stomach contents: Implications for sediment reworking

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Pre-Recent Ross Sea sediments are distinguished by a diatom flora of mixed age whose frustules have undergone considerable chemical dissolution and severe mechanical breakage (Kellogg and Kellogg 1981; Kellogg, Truesdale, and Osterman 1979). We consider the discrepancy in ages of species present in these older sediments and their poor preservation to be hallmarks of reworking. Considering the regional distribution of these sediments, such reworking must have occurred on a very large scale.

Reworked sediments can be produced by the action of bottom currents, former grounded ice sheets, and bottom-dwelling organisms. All three mechanisms might result in some degree of breakage and transport of frustules. Current action can be discounted as the dominant mechanism in most reworked sediment because it would result in obvious size sorting, such as occurs in the relatively rare sediments of the late Glacial-Recent–aged Ross Sea Transition Zone (Kellogg, Osterman, and Stuiver 1979; Kellogg and Truesdale 1979) but not at other levels in Ross Sea cores (Anderson et al. 1980; Kellogg, Truesdale, and Osterman 1979).

In this article, we report the preliminary results of our efforts to distinguish the action of former grounded ice sheets from aspects of bioturbation by epifaunal organisms on the antarctic continental shelf. Our samples were the stomach contents of eight specimens of *Ophionotus victoriae* Bell (Echinodermata: Ophiuroidea) taken on three trawls off the Antarctic Peninsula at water depths of 50 to 80 meters (table 1) (Dearborn, Edwards, and Fratt 1981). This species is one of the most widely distributed and abundant brittle stars on the antarctic continental shelf, occurring at depths of from 5 to at least 750 meters (Dearborn 1977).

First the specimens were dissected and their stomach contents prepared for diatom analysis by standard methods (Schrader 1974). Then nonoverlapping transects of each microslide were examined at a magnification of 1,000 until at least 100 diatom specimens had been identified or half the slides examined.

Table 2 presents our diatom census data. With the possible exception of one questionable specimen of the Pliocene species *Thalassiosira torokina* Brady, all of the 52 species identified currently live in antarctic waters (Fenner, Schrader, and Wienigk 1976; Heiden and Kolbe 1928; Krebs 1977). Individual samples display a high degree of variability in species composition. Only two of the species—*Nitzschia cylindrus* (Grunow) Hasle (dominant in most samples) and *Navicula gelida* var. *parvula* Heiden & Kolbe—occur in all eight samples. Other numerically important species include *Biddulphia weissflogii* Janisch, *Chaetoceros dichaeta* Ehrenberg, *Eucampia antarctica* Castracane, *Nitzschia curta* (van Heurck) Hasle, *N. heimii* Manguin, and *N. turgiduloides* Hasle. Of these, only *N. curta* and *E. antarctica* are abundant in Recent Ross Sea sediments, although *N. cylindrus* often occurs there in low abundances (Truesdale and Kellogg 1979). Most of the remaining species had not been encountered previously in Ross Sea sediments.

Because some of the differences between diatom assemblages in modern Ross Sea sediments and in the stomach contents of ophiuroids from the Antarctic Peninsula may be due to regional differences, a sampling program was carried out during 1981–82 to gather additional *Ophionotus* material together with the top layer of sediment on which they were living. Analyses of these samples will provide the first quantitative data on the relationship between diatom assemblages in antarctic sediments and the feeding habits of ophiuroids, an ecologically important group of macrobenthic invertebrates.

Much of the difference observed in our preliminary study may be ascribed to differences in preservation within sediments. A high proportion of the diatoms from brittle star stomachs were complete, including fine surface markings, suggesting that diatom frustules undergo only a small amount of chemical dissolution and mechanical breakage as they are digested by *Ophionotus victoriae*. Moreover, since all these diatoms are of Recent age, *O. victoriae* apparently disturb only the uppermost layer of sediment and may not mix older and younger sediments significantly.

Severe dissolution and breakage and the mixture of diatom assemblages of various ages in antarctic sediments probably are not caused by feeding and digestive processes in these ecologically dominant organisms. Regional reworking by grounded ice seems the most likely explanation for these features. This does not, however, preclude the possibility of dissolution and breakage of diatom frustules by other groups of benthic invertebrates.

K. Austin prepared the diatom slides. This research was supported by National Science Foundation grants DPP 80-20000 (to T. B. Kellogg and D. E. Kellogg) and DPP 79-21537 (to J. H. Dearborn).

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Table 1. Station details

Station number	Date	General location	Latitude (S)	Longitude (W)	Depth (meters)
6	2/16/81	Argentine Islands	65°14'30"	64°15'24"	50–55
11	2/17/81	Argentine Islands	65°14'06"	64°15'10"	50–60
16	2/22/81	Deception Island	62°50'16"	60°34'15"	50–80

Table 2. Number of specimens of various species found in the stomachs of eight specimens of *Ophionotus victoriae* Bell

	Station 6* specimens			Station 11 specimens			Station 16 specimens	
Taxon	1b	4b	18b	2b	4b	7b	4b	175b
Biddulphia anthropomorpha van Heurck (1909)	0	0	0	0	1	0	0	0
Biddulphia weissfloggii Janisch (1862)	8	4	1	1	2	2	0	1
Biddulphia Gray (1821) sp.	1	0	0	0	0	0	0	1
Chaetoceros atlanticus Cleve (1873)	0	0	0	10?	0	0	0	0
Chaetoceros castracanei Karsten (1905)	0	0	0	0	4	0	0	0
Chaetoceros dichaeta Ehrenberg (1844)	0	9	2	15?	5	15	3?	0
Chaetoceros sp. cf. *adelianum* Manguin (1957)	0	0	0	0	0	0	11?	0
Chaetoceros Ehrenberg (1844) spp.	3	4	0	2	0	0	0	0
Charcotia actinochilus (Ehrenberg) Hustedt (1958)	0	0	0	0	0	2	0	1
Cocconeis curiosa Hustedt (1958)	0	0	0	0	1?	1?	0	0
Cocconeis imperatrix A. Schmidt (1894)	0	0	0	1	1	3	1	0
Cocconeis schuettii van Heurck (1909)	0	1	0	0	0	0	0	0
Corethron criophilum Castracane (1886)	0	0	1	2	0	0	0	0
Corethron Castracane (1886) sp.	1	0	0	0	0	0	0	0
Coscinodiscus lentiginosus Janisch *in* A. Schmidt (1978)	1	0	0	0	0	0	0	0
Coscinodiscus stellaris var. *symbolophorus* (Grunow) Jørgensen (1905)	0	0	0	0	0	0	0	3
Cyclotella compta (Ehrenberg) Kützing (1849)	0	0	0	0	0	0	0	1
Cyclotella glomerata Bachmann (1911)	0	0	0	2	0	0	0	4
Cyclotella stelligera Cleve & Grunow *in* van Heurck (1881)	1	0	0	4	0	0	0	0
Diploneis Ehrenberg (1845) sp.	0	0	0	0	0	0	1	0
Entomoneis paludosa (W. Smith) Reimer (1975)	1?	0	0	0	0	0	0	0
Eucampia antarctica (= *E. balaustium*) Castracane (1886)	11	2	14	4	2	3	0	0
Hantzschia amphioxys (Ehrenberg) Grunow (1877)	0	0	0	0	0	0	0	1?
Hemidiscus karstenii Jouse (1962)	1	0	0	0	0	0	0	0
Licmophora decora Heiden & Kolbe (1928)	0	0	0	0	0	0	7	0
Licmophora Agardh (1827) sp.	0	0	0	0	0	0	0	1
Melosira distans (Ehrenberg) Kützing (1844)	0	0	0	0	0	0	0	1
Melosira italica var. *subarctica* Müller (1906)	0	0	0	0	0	0	0	1
Navicula directa (W. Smith) Ralfs *in* Pritchard (1861)	2	0	0	0	0	2	2	0
Navicula gelida var. *parvula* Heiden & Kolbe (1928)	4	5	1	8	1	11	2?	4
Navicula Bory (1822) spp.	0	0	2	0	2	0	0	4
Nitzschia closterium (Ehrenberg) W. Smith (1853)	5	1	3	0	1	2	0	0
Nitzschia curta (van Heurck) Hasle (1972)	3	2	14	9	3	12	0	1
Nitzschia cylindrus (Grunow) Hasle (1972)	65	79	30	88	131	167	6	14
Nitzschia heimii (Manguin) Hasle (1965)	40	15	2	21	13	11	0	1
Nitzschia kerguelensis (O'Meara) Hasle (1972)	0	0	0	0	0	0	0	2
Nitzschia obliquecostata (van Heurck) Hasle (1972)	25?	10?	0	0	0	1	0	0
Nitzschia separanda (Hustedt) Hasle (1972)	0	0	0	0	1	0	0	0
Nitzschia sublineata (Hustedt) Hasle (1972)	0	0	0	0	5	0	0	0
Nitzschia turgiduloides Hasle (1965)	0	0	2	2	9	37	0	1
Nitzschia Hassal (1845) sp.	0	0	0	1	0	0	0	0
Pleurosigma W. Smith (1853) sp.	0	0	0	0	0	0	1	0
Schimperiella antarctica Karsten (1905)	0	0	1	0	0	1	0	0
Synedra kerguelensis Heiden & Kolbe (1928)	0	0	0	0	0	0	0	20
Tabellaria quadriseptata Knudson (1952)	1	0	0	2	0	0	0	0
Thalassionema nitzschioides Grunow *in* van Heurck (1881)	5	3	0	0	0	0	0	0
Thalassiosira antarctica Comber (1896)	0	0	0	5	3	3	0	0
Thalassiosira delicatula Hustedt (1958)	0	0	0	0	0	0	0	5
Thalassiosira gracilis (Karsten) Hustedt (1958)	0	0	0	0	0	0	0	1
Thalassiosira torokina Brady (1977)	0	0	0	0	0	0	0	1?
Thalassiosira Cleve (1873) spp.	11	4	3	0	0	0	3	0
Thalassiothrix longissima Cleve & Grunow (1880)	1	2	1	0	1	0	0	0
Total	190	141	77	179	191	273	37	69
Number of transects examined	10	10	9	10	10	5	10	10

*See table 1 for location of stations.

Effect of hydrostatic pressure and temperature on krill growth

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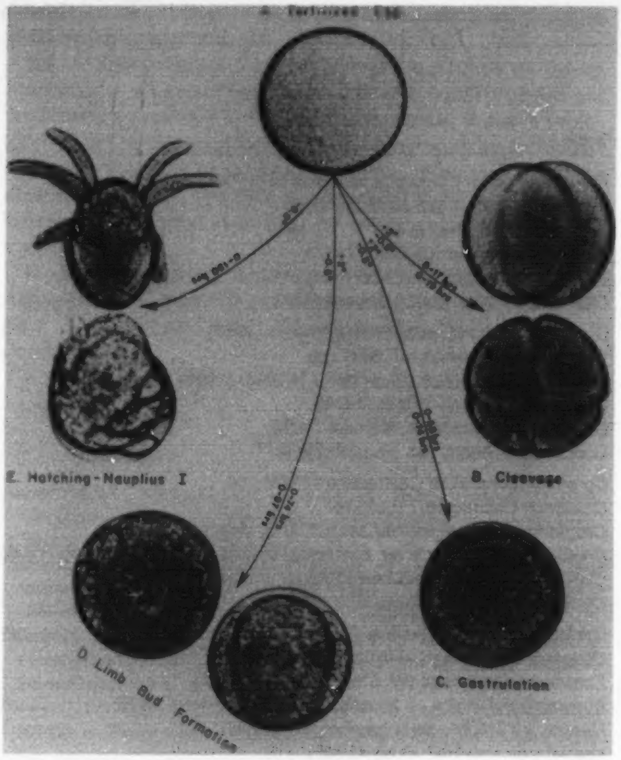
During the austral summer (December 1981–April 1982), the effect of temperature and pressure on the developing eggs of the antarctic krill, *Euphausia superba*, and the pressure acclimation levels of the different ontogenetic stages of the krill were investigated. All embryological studies were performed at −0.5°C and 2°C and at pressures ranging from 1 to 250 atmospheres.

The field effort was undertaken aboard R/V *Hero* in Croker Passage and Charlotte Bay in the Bransfield Strait. Krill larvae (furcilia) at various stages and adult as well as gravid krill were captured from krill swarms and transported alive to aquaria at Palmer Station. A new experimental system having television and videotaping features was used for the pressure experiments.

Experiments on the effect of pressure on the various stages of developing krill eggs showed that cleaving eggs are inhibited from progressive development when exposed to high pressure (250 atmospheres). However, gastrulation was evident on krill eggs maintained at 40 atmospheres for 48 hours, and development from nauplius stage I to II was observed at 100 atmospheres for 24 hours. We also observed formation of abnormal eggs under certain hydrostatic pressure levels. At 50 atmospheres, cleaving eggs at the two- to four-cell stage reversed to the one-cell stage.

We have determined the time sequence of progressive development of krill eggs, from newly spawned to hatching of nauplius I larvae, at −0.5°C, but we encountered significant mortality at the onset of gastrulation at 2°C. Cleavage, blastula formation, and the initiation of the gastrulation process do not seem to differ significantly at these two temperatures. The average time of appearance of gastrula in the culture was 32 hours at 2°C and 35 hours at −0.5°C (figure). However, gastrulation did not persist as long at 2°C as at the negative temperature. This was also true of the next embryonic stage of limb bud formation. The mean time to reach limb bud stage at positive temperature was 59 hours; at negative temperature, it was delayed to 76 hours. Preliminary data on survival of nauplii I and II indicate that, at certain threshold levels of selected amino acids, these early krill larvae exhibit healthy movement concomitant with high survival rates. This finding suggests apparent uptake of dissolved organic substances for energetics involving possible synthesis of protein or lipids that may account for the larval ascending phenomenon (George in preparation).



Embryonic stages of developing krill eggs from spawning to hatching of nauplius I. Note the time sequence in development at −0.5°C and 2°C.

This research is the first to establish that krill at different ontogenetic stages adapt differently to pressure. The nauplii larvae showed the greatest ability to acclimate to higher levels of pressure (210 atmospheres for nauplius I and 150 atmospheres for nauplius II). Also, postlarval krill and immature adults exhibited a higher potential for acclimation to pressure than did adult males and gravid females. The data suggest that egg-bearing females cannot withstand pressures exceeding 25 atmospheres (equivalent to 250 meters); therefore, krill cannot spawn in depths exceeding 250 meters.

This research was supported by National Science Foundation grant DPP 80-26535.

Reference

George, R. Y. In preparation. *Ontogenetic adaptations in growth and metabolism of* Euphausia superba *in relation to temperature and pressure.*

Protein synthesis studies in icefishes and nototheniids

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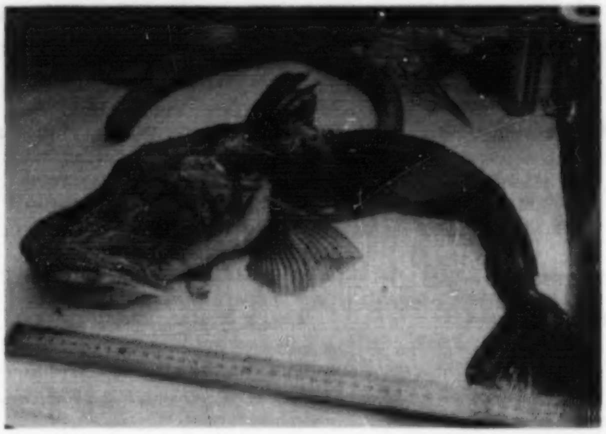

Figure 1. *Chaenocephalus aceratus*, 1.8-kilogram female, ovary weight 140 grams.

Adaptation to cold involves adjustments in biochemical systems that allow antarctic fish to maintain adequate metabolic rates despite the strongly rate-depressing effects of low body temperature. In fishes of McMurdo Sound, rates of protein synthesis are two to three times those expected at the habitat temperature of −1.8°C (Smith and Haschemeyer 1980). The system, however, is unusually sensitive to elevated temperatures. Synthetic rates in liver were found to increase normally with temperature only up to 7°C both *in vivo* (Haschemeyer 1982) and in hepatocyte culture (Haschemeyer and Mathews in press). This sensitivity may account for the very low incipient lethal temperature of 6°C reported in these species (Somero and DeVries 1967). In contrast, cell-free protein synthetic systems are active from 0°C to 30°C (Haschemeyer and Williams 1982).

During the past field season (January–February 1982) at Palmer Station we initiated studies on protein synthetic adaptations in peninsular fishes, including the hemoglobin-free icefishes. Good yields of the nototheniids *Notothenia coriiceps neglecta* and *N. gibberifrons* and of the channichthyd *Chaenocephalus aceratus* were obtained by trawling from the R/V *Hero* in Dallman Bay and at Low Island. Specimens of *N. larseni, N. rossii, N. nudifrons, Chionodraco hamatus, Parachaenichthys charcoti*, and *Lycenchelys nigripalatum* also were collected. Data on body weight and reproductive status are summarized in table 1. *C. aceratus* (figure 1) and *Ch. hamatus* showed advanced ovary development. Blood and DNA samples were obtained from all species. Protein synthesis experiments were carried out *in vivo*, using a pulse injection into the caudal vein of 150 millimolars of carbon-14–phenylalanine (220 disintegrations per minute per nanomole) at a total dose of 45 micromoles per 100 grams of body weight. Specific radioactivity of l-phenylalanine in protein-bound form and in tissue-free pools was determined after various times by fluorometry and scintillation counting; this was used to calculate the percentage of tissue protein synthesized per day by the method of Garlick, McNurlan, and Preedy (1980).

Table 2 summarizes the results of preliminary data analysis. Rates for muscle in feeding fish and for liver (including plasma protein synthesis) in all fish averaged two to three times those predicted for temperate fish (Smith and Haschemeyer 1980), indicative of adaptation to cold. Nonfeeding fish showed increased synthetic activity in liver (relative to liver protein content) and significantly reduced activity in muscle, the latter

Table 1. Body weights and gonad and liver data for fish collected near Palmer Station, January 1982

Species	Sex	Body weight (grams)	gonad weight / body weight (percentage)	liver weight / body weight (percentage)	Ovary protein (mg/g wet weight)
Chaenocephalus aceratus	M	350–840	1.6 ± 0.7 (10)[a]	3.0 ± 1.0 (10)	N.D.[b]
	F	510–2,210	11.2 ± 2.0 (13)	6.6 ± 0.8 (13)	132 ± 19 (8)
Notothenia coriiceps	M	580–1,630	4.6 ± 0.9 (14)	2.5 ± 0.8 (14)	N.D.
neglecta	F	930–1,400	6.7 ± 2.4 (7)	4.4 ± 0.9 (7)	110 ± 17 (5)
N. gibberifrons	M&F	340–610	1.5 ± 0.6 (6)	1.2 ± 0.2 (5)	65 ± 2 (3)
N. nudifrons	M&F	30–40	N.D.	2.3 (7)[c]	N.D.
N. rossii	F	55–60	3.5 ± 0.2 (2)	N.D.	63 ± 2 (2)
Chionodraco hamatus	M	495	2.0 (1)	1.8	N.D.
	F	510	10.6 (1)	5.6	N.D.
Lycenchelys nigripalatum	M	97	0.25 (1)	2.0	N.D.

[a] Mean ± 1 standard deviation; numbers in parentheses indicate number of fish measured.

[b] N.D. = not determined.

[c] The seven fish (bodies and livers) were measured together; hence no standard deviations.

Table 2. Protein synthetic rates in tissues of *Notothenia coriiceps* and *Chaenocephalus aceratus*

Species	Exposure temperature	Length of exposure (hours)	Feeding	Percentage of tissue protein synthesized per day		
				Liver	Muscle	Head kidney
Notothenia coriiceps neglecta	2°C	10–30	+	8.6 ± 1.7 (3)*	0.30 ± 0.02	3.3 ± 0.3
		10–30	–	11.7 ± 3.2 (3)	0.19 ± 0.03	5.2 ± 1.2
	4°–8°C	30	+	4.4	0.61	4.0
		20	–	11.1	0.39	6.5
Chaenocephalus aceratus	2°C	20–30	–	9.8 ± 0.3 (2)	0.12 ± 0.1	3.5 ± 0.3

*Mean ± 1 standard deviation; numbers in parentheses indicate numbers of animals measured.

reflecting the loss of muscle protein synthesis directed to growth. Two fish warmed to 4–8°C showed a normal temperature-dependent increase of rate in muscle but not in liver. This is particularly evident in the individual exposed for 30 hours. These data are the first evidence of a differential response of fish tissues to temperature change.

Experiments on protein synthesis in the hematopoietic head kidney of these species were initiated in an effort to account for

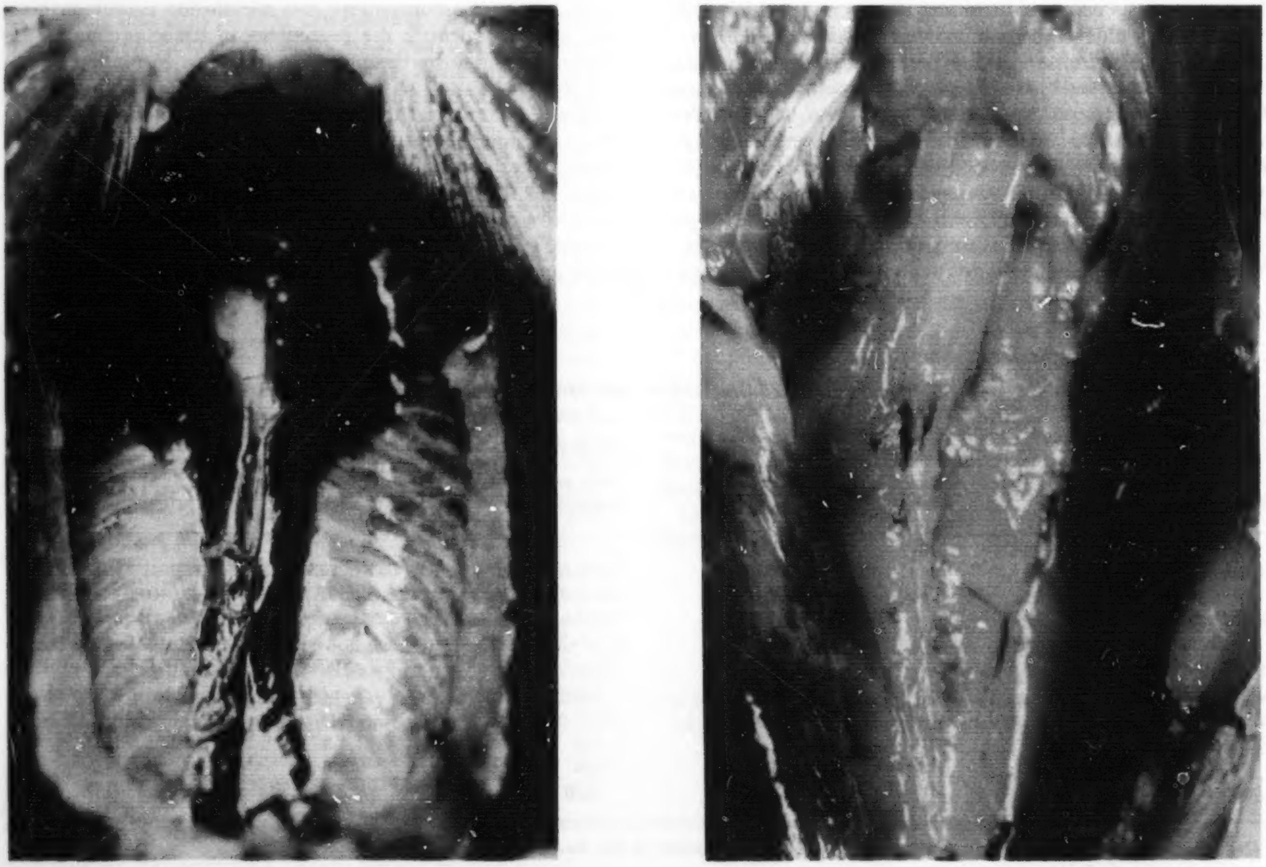

Figure 2. The head kidney (upper) and trunk kidney (lower) in the notothenliid *N. coriiceps* (left) and the icefish *C. aceratus* (right).

the failure of hemoglobin synthesis and red blood cell development in the icefishes. Erythrocytelike cells were present at concentrations of only 0.03–0.1 × 10^9 cells per milliliter in plasma of *C. aceratus* and *Ch. hamatus*, compared with values averaging 11 × 10^9 in the four nototheniid species and 17 × 10^9 in *L. nigripalatum*. The appearance of the head kidney and trunk kidney of *C. aceratus* resembled that of *N. coriiceps* (figure 2) except for the almost complete absense of pigmentation. The amount of head kidney as a percentage of body weight was 0.56 ± 0.23 in *C. aceratus* (12 animals measured) and 0.65 ± 0.15 in *N. coriiceps* (12 animals measured). The results in table 2 indicate high rates of protein synthesis in head kidney of both species. Future studies will examine the distribution of proteins synthesized.

The field party included A. Haschemeyer, G. DiPrisco, S. Rappaport, H. Jannasch, and R. Devereaux. The project was supported by National Science Foundation grant DPP 80-21454.

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Temperature and levels of glycopeptide antifreeze in antarctic fishes

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Our field season began in early October 1981 with the arrival of W. Van Voorhies, S. Munsell, and J. Alhgren of the University of Illinois. R. Williams of Vanderbilt University, D. Powers of Johns Hopkins University, and J. C. Ellory of the Physiological Research Laboratory, Cambridge University, joined the group during the latter part of the season.

Two fishing stations were established on the ice of McMurdo Sound and were maintained until late December, when sea-ice conditions became too hazardous to support the vehicles used to move the fish houses across the tidal crack. From these stations, specimens of the various *Trematomus* fishes and 300 specimens of the large antarctic cod, *Dissostichus mawsoni*, were obtained. Most of the *Dissostichus* were too large for our experiments and thus were weighed, measured, tagged in three places, and released. Some of the smaller specimens were transported to the Jamesway aquarium and used for studies of the distribution of antifreeze in the bile, intestinal fluid, and other tissues spaces, and for studies of glycopeptide antifreeze turnover.

One of the *Dissostichus* had been captured 7 years earlier. The three tags were intact, and the tissue surrounding them showed little erosion or tissue reaction to the tag. Over the 7 years the fish had increased in length from 120 to 141 centimeters, and in weight from 21.7 to 37.6 kilograms. It appeared to be healthy and well fed. The recapture indicates that this species returns to McMurdo Sound; its rate of growth is moderate despite the low water temperatures of the high latitudes of the southern ocean.

This season also marked the completion of our studies of the effects of warm acclimation on the concentration and synthetic rate of antifreeze glycopeptides in antarctic fishes. To examine the problem we acclimated two groups of *Pagothenia borchgrevinki* for 7 weeks, one group at +4°C (warm acclimation) and the other at −1.5°C (environmental temperature of −1.9°C). The effect of temperature on rate of synthesis of antifreeze glycopeptide was investigated using isolated hepatocytes in culture over a 5-day time course. Cell viability was monitored by trypan blue staining, INT Formazan incorporation, and incorporation of carbon-14–leucine into TCA (trichloroacetic acid) precipitable protein. The isolated hepatocytes effectively incorporated labeled amino acids for 5 days. Incorporation of hydrogen-3–alanine into antifreeze glycopeptides followed Michaelis-Menton kinetics, with a maximum velocity of 20 and 32 nanomoles per milligram of protein per hour at −1.5°C and +4°C, respectively. Polyacrylimide gel electrophoresis showed that isolated hepatocytes synthesize all four antifreeze fractions found in the serum of *P. borchgrevinki* (O'Grady, Clarke, and DeVries 1982).

The table shows the freezing point depressing activity of antifreeze glycopeptides from the serum of warm- and cold-acclimated fishes. Warm acclimation had little effect on the levels of antifreeze glycopeptide in the serum. Since antifreeze glycopeptides have a long turnover time—3 weeks or more (DeVries 1974)—this finding suggested that changes in levels of antifreeze mRNA (messenger RNA) had occurred that could not be detected by changes in antifreeze activity in the serum. Therefore, we examined the effects of warm acclimation on levels of antifreeze mRNA by indirectly comparing translational activity from warm- and cold-acclimated specimens using a cell-free translation system.

Figure 1 shows a comparison of wheat germ translation products from poly A containing RNA from the black cod, *Notothenia angustata*, and from *D. mawsoni*. Translation products corresponding to antifreeze glycopeptides in *D. mawsoni* were deter-

Quantitation of wheat germ-translatable antifreeze glycopeptide mRNA from warm- and cold-acclimated *P. borchgrevinki*

Number	Acclimation temperature	Melting point (M.P.) ± S.E.	Freezing point (F.P.) ± S.E.	F.P. − M.P.	Total counts per μg RNA*	Immunoprecipitable counts*
6	−1.5°C	−1.13°C ± 0.03	−2.71°C ± 0.05	1.58°C	13,455	4,125
					10,268	2,634
					11,132	2,861
					(11,618)	(3,206)
8	4°C	−1.11°C ± 0.04	−2.64°C ± 0.06	1.53°C	11,360	2,842
					14,258	3,816
					12,875	3,355
					(12,831)	(3,338)

*Counts are for three animals in each acclimation group; numbers in parentheses are means.

mined by specific immuno precipitation with an antibody that reacts with the peptide portion of the glycopeptide. Antifreeze translation products are not present in the black cod; nor does this fish synthesize an antifreeze in nature. Translational activity of mRNA isolated from equal amounts of liver from three warm- and three cold-acclimated *P. borchgrevinki* is shown in the table. Immuno precipitation of translation products with glycopeptide antifreeze antibody indicates that no significant change in antifreeze glycopeptide RNA occurred as a result of acclimation (O'Grady and DeVries in preparation).

Antifreeze glycopeptides isolated in large amounts from the blood of *D. mawsoni* were used to investigate the antifreeze properties of glycopeptide 6. This glycopeptide was resolved into four bands by electrophoresis, using a fluorescent stain, and its antifreeze activity was compared with that of a glycopeptide similar in molecular weight isolated from the Atlantic tomcod, *Microgadus tomcod* (O'Grady et al. in press). The purified glycopeptides also were used to investigate the relationship of amino acid composition and size to freezing point depression. Variations in the amino acid composition of similar-sized glycopeptides had no effect on the freezing point depression of similar-sized, low-molecular-weight glycopeptides when compared on a weight basis (Schrag, O'Grady, and DeVries in press). Glycopeptides 6, 7, and 8 from *D. mawsoni* contain significant amounts of proline, which replaces alanine, while glycopeptides from the arctic cod, *Eleginus gracilis*, contain both proline and arginine, which replace both alanine and threonine. Comparisons of antifreeze activity of individual glycopeptides on a molar basis indicated that the effectiveness of the antifreeze glycopeptides is related to molecular size and not to differences in amino acid composition. The large glycopeptides produce a larger depression of the freezing point of water than the small ones. (See figure 2).

The purified large and small glycopeptides also were used to investigate the cooperativity phenomenon (Mulvihill et al. 1980; Osuga et al. 1978). Measurements of the noncolligative freezing point depression of water by the various antifreeze glycopeptides, using a freezing point osmometer, have lead to the designation of active glycopeptides 1 through 5 and inactive glycopeptides 6, 7, and 8. The latter show only a colligative depression of the freezing point when freezing points are determined with a freezing point osmometer. Measurements using a freezing point osmometer (Osuga et al. 1978) indicated that the presence of a small amount of glycopeptides 1 through 5 potentiated the noncolligative freezing point depressing activity of glycopeptides 7 and 8. With this technique, freezing occurs very rapidly because samples are supercooled by approximately 4°C, significantly affecting antifreeze activity. When the

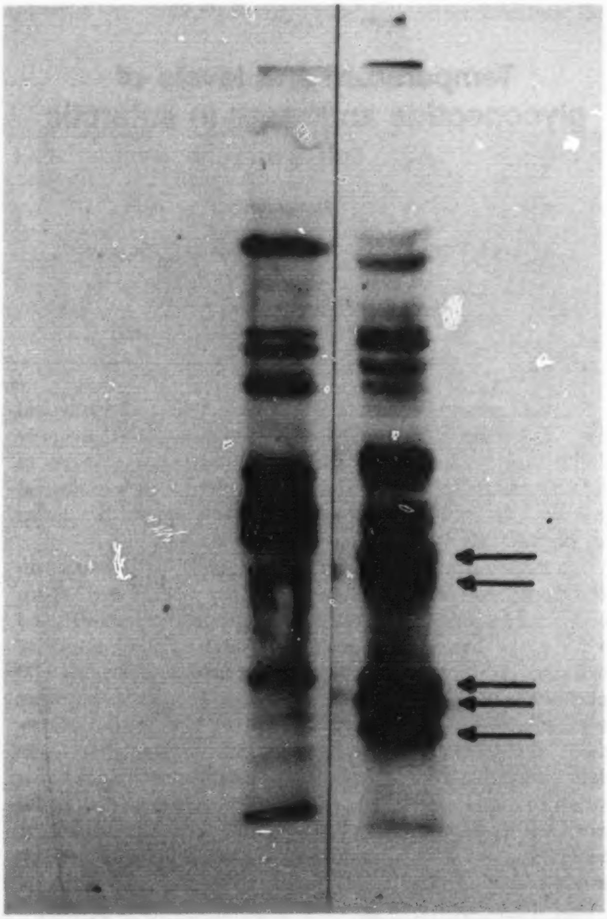

Figure 1. Comparison of wheat germ translation products from two nototheniid fishes, the black cod, *Notothenia angustata* (left), and the antarctic cod, *Dissostichus mawsoni* (right). Antifreeze translation products are indicated with arrows.

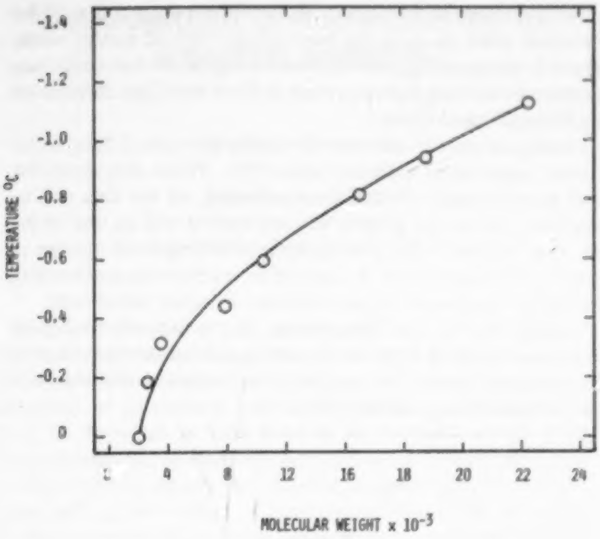

Figure 2. Relationship between freezing point depression and molecular weight. All concentrations are 1 millimolar.

antifreeze activity of glycopeptides 6, 7, and 8 is determined visually by determining the temperature at which a small seed crystal grows as the temperature is lowered slowly (0.01°C per minute), the small antifreeze glycopeptides show two-thirds the activity of glycopeptides 1 through 5 when compared on a weight basis. Thus, with slow cooling, the small glycopeptides show antifreeze activity or a significant noncolligative lowering of the freezing point (Duman and DeVries 1972). Addition of small amounts of glycopeptides 1 through 5 to the small glycopeptides does not produce the potentiation described when a freezing point osmometer is used (Schrag and DeVries in press).

The potentiation of antifreeze activity of the large glycopeptides on the small glycopeptides most likely is associated with rapid freezing in the freezing point osmometer and is of no biological relevance, because fishes would never be exposed in nature to 4 degrees of supercooling. Polar fishes seldom freeze in their natural environment. If they are exposed to freezing conditions the cooling of these fish to the freezing point is gradual; under such conditions the low-molecular-weight glycopeptides would exhibit antifreeze activity and thus play a vital role in avoidance of freezing.

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Population studies of the south polar skua

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Most of what is known about seabirds concerns their social behavior and breeding biology, that is, the part of their natural history leading up to and culminating in the fledging of young. We know only a little about population biology—the information on adult survivorship, mortality, and longevity needed to place data on breeding productivity in perspective. It is the adjustment between fledging success rates and postfledging young and adult survival rates that determines whether population size changes or remains stable. Both types of data are needed to construct a species' life table and to understand changes in population size, since environmental change can affect either or both of the rates.

We are studying the population biology of the south polar skua (*Catharacta maccormicki*) at Cape Crozier, Ross Island. The project actually began in the 1961–62 season, the first of nine consecutive seasons in which Robert C. Wood banded all chicks that hatched and survived to about 2 weeks of age. When these birds returned as subadults and adults in subsequent years, their presence and breeding behavior were recorded. Using these data, we can analyze demographic characteristics for birds up to 8 years of age.

The project was discontinued after 1970–71 except for 2 years of censuses made by David G. Ainley in 1974–75 and 1975–76 (birds 5–14 years old). Then in 1980–81 we began a 3-year effort to collect data on the oldest birds (11–20 years).

During the past season, 1981–82, we returned to Cape Crozier for 3 weeks and censused known-age skuas again. Comparison of this season's and last season's figures indicates an annual survivorship close to 99 percent in the oldest birds; previous study of breeding birds of unknown ages showed an average survivorship of 94 percent over 4 years (Wood 1971).

We also surveyed, with helicopter and ice breaker support, all skua rookeries elsewhere on Ross Island, on the mainland coast of McMurdo Sound, and on the Victoria Land coast and adjacent islands between Cape Adare and Terra Nova Bay. We were looking for skuas that had hatched and been banded at Cape Crozier in order to calculate emigration rates (this information is critical for adjusting the demographic parameters based on our studies at Crozier). We found only four Crozier birds, both from the two larger year-classes, indicating very low emigration rates in this population.

We also were able to estimate the total Ross Sea population for the south polar skua on the basis of our 1981–82 survey work. About 3,900 breeding pairs exist in the region, and an unknown number are nesting between Marble Point and Cape Roberts on the Victoria Land Coast.

During the past 2 years we have computerized all data on the Crozier population gathered since 1961. When data from the final year of study (1982–83) are collected, all the data will be analyzed. When the project is completed it will be one of the few that considers the demography of a long-lived species of seabird. This unique set of data will be useful in understanding the factors that regulate populations of higher vertebrates.

During 1981–82, Phil Henderson, Steve Morrell, and Judy Sherburne assisted in the field and Chris Ribic performed all of the computer work. This project is supported by National Science Foundation grant DPP 79-20796.

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Comparative ecology of south polar and brown skuas at Palmer Station

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From 28 December 1980 to 1 April 1981, a comparative study of south polar skua (*Catharacta maccormicki*) and brown skua (*C. lonnbergi*) ecology continued at Palmer Station. This was the final season for making time budget observations on adult skuas, for weighing and measuring eggs, chicks, and adults, and for sound and film recording of adult displays. Data collection included 762 bird-hours of time budget observations, determination of growth rates of chicks from 18 nests, and banding of 80 chicks and 10 adults.

In contrast to the previous year (Pietz and Maxson 1980), south polar skuas did not appear to be suffering from a lack of food at the beginning of the breeding season. Early departure of ice from surrounding waters apparently allowed access to rich fishing areas. This resulted in earlier egg laying, a greater number of nests, and more eggs per nest than in the previous season. However, total productivity, as measured by number of fledglings, was not as great. Scarcity of food and numerous storms late in the season led to massive chick mortality.

As in other years, most brown skuas nested earlier than the south polar skuas and fed almost exclusively on penguin eggs and chicks and on spilled krill obtained in penguin colonies. Productivity was lower than in the previous year because of higher chick mortality and fewer nesting pairs.

Several brown skua territories left vacant by the fowl cholera outbreak of February 1979 (Parmelee, Maxson, and Bernstein 1979) were reoccupied this season. Three were claimed by brown skua pairs, none of which nested successfully. Several others were occupied by breeding south polar pairs, which made unprecedented use of the adjacent penguin food supply.

Only one mixed pair was observed this year; it produced one hybrid fledgling. Although numerous skuas banded as chicks during the past 6 years returned to the Palmer area, none of the hybrids from previous seasons was seen during the 1980–81 season. However, a 4-year-old hybrid that had been banded as a chick at Palmer, by William Fraser, was recovered at Paranagua, Brazil, on 23 May 1980.

The help of numerous scientists and station personnel made this work possible; special thanks go to M. Larkin, D. Johnson, R. Watkins, and R. Williams. This study was supported by National Science Foundation grant DPP 77-22096 to D. F. Parmelee.

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Development of homeothermy in antarctic seabirds

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Newly hatched chicks of seabirds differ in their ability to maintain their body temperatures at a high level. At one extreme, the hatchlings of altricial species have no down, are incapable of generating heat in response to cold stress, and must be brooded by their parents to maintain a high body temperature. At the other extreme, precocial species hatch with a thick layer of down, are capable of generating body heat, principally by shivering, and require relatively little brooding by their parents (Nice 1962). Between these two extremes is a range of developmental types. Regardless of the level of homeothermy at hatching, the subsequent increase in temperature regulation during the development period depends on an increase in the chick's ability to generate heat combined with a decrease in thermal conductance across the chick's surface. Increase in metabolic response to cold stress normally is associated with an increase in the size and degree of functional maturity of skeletal muscles (Calder and King 1974). Decreased thermal conductance results from the development of a thick layer of down, which eventually is replaced by feathers in the juvenile bird (see, e.g., Spiers, McNabb, and McNabb 1974).

One goal of our research on the energetics of reproduction in seabirds at Palmer Station during January and February 1981 was to characterize the development of homeothermy in the large seabirds that inhabit the area (see Parmelee, Fraser, and Neilson 1977). Although all the species are exposed to extremely cold temperatures, generally in the range of 0° to 5°C, seabirds exhibit a variety of development types, ranging from an extreme altricial species, the blue-eyed shag (*Phalacrocorax atriceps*), to a precocial species, the south polar skua (*Stercorarius maccormicki*). Intermediate between these are two species, the Adélie penguin (*Pygoscelis adeliae*) and the southern giant fulmar (*Macronectes giganteus*), whose hatchlings are downy but are brooded by their parents for an extended period. This article reports on body temperatures of undisturbed chicks, as an index to the normal temperature during early development, and on the rate of decrease in body temperature when exposed to cold stress.

Body temperatures were measured by inserting a thermistor (Yellow-Springs Instruments) into the proventriculus. Air temperature was measured by placing the same thermistor probe in a shady spot 0.5 meter above the ground. Loss of body heat was determined by placing chicks in wire baskets in a location similar to the natural nest site and recording the body temperature at the beginning and end of a 30-minute trial period. Air temperatures during these experiments varied between 0° and 10°C. Temperature loss is presented as the coefficient of homeothermy:

$$H = \frac{(T_f - T_a)}{(T_i - T_a)} \times 100,$$

where T_a is the ambient air temperature, T_i is the initial body temperature of the chick, and T_f is the body temperature at the end of the trial period. H is the gradient between the temperature of the chick and that of its surroundings at the end of a 30-minute period, expressed as a percentage of the gradient at the beginning of the period. When there is no change in body temperature during the trial, the coefficient is 100 percent. If body temperature were to drop to the ambient temperature during the trial, the coefficient would be 0 percent.

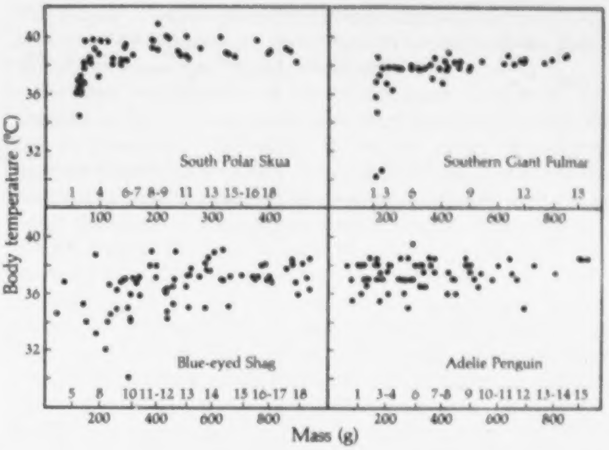

Figure 1. Body temperatures of chicks of four species of seabirds at Palmer Station, plotted as a function of body mass. Note the different scale for the south polar skua. Approximate ages of the chicks, in days, are shown just above the horizontal scales.

Body temperatures of chicks at their nests are presented in figure 1. Temperatures are plotted with respect to the mass of the chick so that comparisons among the species can be made on a mass-specific basis. Comparisons among adult birds have shown the relationships between heat generation and conservation to be closely related to size (Calder and King 1974). For convenience, figure 1 gives approximate ages of chicks, in days, along with the mass scale. Of the four species, the blue-eyed shag had the most variable body temperatures during the early growth period and was the last to develop effective control of body temperature. The other three species exhibited decreased body temperatures only during the first couple of days after hatching. The two low values (between 30° and 31°C) for the southern giant fulmar were obtained from recently hatched chicks whose down had not yet fully dried. After homeothermy had been achieved, the body temperatures of chicks were between 36° and 38°C in the shag, about 38°C in the penguin and giant fulmar, and between 38° and 40°C in the skua.

The coefficient of homeothermy is plotted as a function of body mass in figure 2. Both the skua and giant fulmar had well-developed homeothermy, virtually from hatching, when exposed to temperatures of between 0° and 10°C. Two coefficients of homeothermy (H) of less than 80 percent were obtained from skuas less than 1 day old. Subsequently, all skua chicks had values of H greater than 90 percent. Within 5 days of hatching, all giant fulmar chicks had values of H greater than 90 percent. The shag and, to a lesser degree, the penguin had poorly developed homeothermic abilities at hatching. Hatchling penguins exhibited H values of about 60 percent, but even after 1

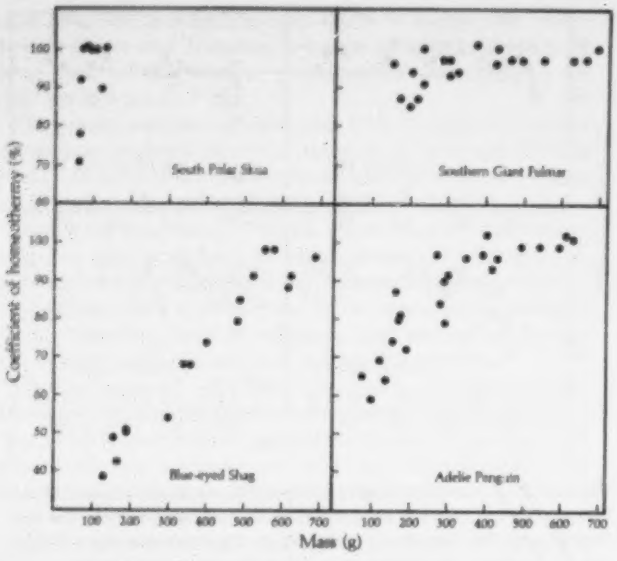

Figure 2. Coefficient of homeothermy for four species of seabirds at Palmer Station, plotted as a function of body mass. The values were determined at ambient temperatures between 0° and 10°C over periods of 30 minutes.

week shag chicks had values below 50 percent. Penguin chicks achieved *H* values exceeding 90 percent at a mass of about 300 grams (about 1 week), but shag chicks did not achieve a similar level until about 600 grams (about 14–15 days after hatching). Homeothermic capacities, as illustrated by the coefficient *H*, agree quite well with the variability in body temperatures of chicks at the nest during the early part of the growth period. The relatively constant body temperatures of penguin chicks, even from an early age (figure 1), indicate the effectiveness of parental brooding in maintaining body temperature. The considerably more variable body temperatures of shags indicate less precise control.

Since rate of heat loss is a function of both the ability of the chick to generate heat and the capacity of the chick to retain that heat by surface insulation, it is not surprising that the coefficient of homeothermy is closely related to the length of the hatchling's down: 0 millimeters in the shag, approximately 7–10 millimeters in the penguin, 15–20 millimeters in the skua, and 25–30 millimeters in the giant fulmar.

Variation among species in the development of homeothermy is not clearly related to characteristics of the environment. Thermal conditions at the nests of all four of the species in this study are similar. Yet the type of development and the corresponding intensity of parental care vary considerably between the altricial shag and the precocial skua. Development type is consistent, however, within a taxonomic category (Nice 1962). For example, all shags and cormorants exhibit altricial development, regardless of the climate. The double-crested cormorant in Maine, for example, achieves a value of *H* of 75 percent at about 500 grams body mass (Dunn 1975), which is similar to the blue-eyed shag. The Guanay cormorant of Peru achieves homeothermy at about the same pace (Duffy and Ricklefs 1981). In contrast to the shags, most species of skua and their close relatives, the gulls, exhibit relatively little brooding by the parents and an early development of temperature regulation regardless of geographical locality. Among the petrels and their relatives (Procellariiformes), most of the species that nest on the ground surface have a period of parental brooding, usually 1 to 2 weeks long. Generally, these species do not hatch with fully develped temperature control, whereas their close burrow-nesting relatives, for example, shearwaters and much smaller storm-petrels, are essentially thermally independent from hatching (Ricklefs, White, and Cullen 1980).

The extent of parental brooding does not appear to be correlated to the distance between breeding sites and foraging areas. The shags and the skuas feed close to the nesting areas and yet exhibit the extremes in development type. Both giant fulmars and Adélie penguins feed at some distance from their nests, returning infrequently to their chicks, but they brood their young for periods of up to 2–3 weeks.

Predation might affect the pattern of parental care. The threat of predators, principally the south polar skua in the Palmer Station area, requires the parents in several species to guard their chicks for extended periods. Shags, penguins, and skuas themselves are particularly vulnerable to attack during the early part of the growth period. It is not known whether giant fulmar chicks are susceptible to skua attack at an early age, but parents do stay at the nest site for a week or more after they stop brooding the chick. Again, there seems to be no relationship between presence at the nest site to defend the chicks against predators and the development of temperature regulation by the chicks.

This work was supported by National Science Foundation grant DPP 79-08570 to the University of Pennsylvania. The field team consisted of R. E. Ricklefs, J. B. Williams, and K. K. Matthew. I am grateful for the logistical support of the U.S. Antarctic Research Program and for the advice and support of the scientific and support staff at Palmer Station, especially Director D. Wiggin.

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Distribution and abundance of marine birds in the Ross and Bellingshausen Seas

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The object of this study was to examine the distribution and abundance of marine birds in the Ross and Bellingshausen Seas. In particular, I wished to test the hypothesis of Ainley and Jacobs (1981) that there is a significant increase in avian numbers and biomass associated with a subsurface front at the edge of the Ross Sea continental shelf. More broadly, I sought evidence of patterns in distributions of marine birds that might reflect aspects of surface or subsurface oceanographic conditions.

Information on bird density was obtained between 3 and 13 January during 375 10-minute transects of the USCGC *Glacier* from southwest of Scott Island to the northern Victoria Land coast and southward along the coast; observation was continuous or nearly continuous. A second set of 689 10-minute transects was made between 29 January and 7 February 1982 from McMurdo Sound, Ross Island, to Palmer Station; coverage on this second set of transects was essentially continuous during daylight hours from the northern portion of the Ross Sea.

Observations were made from the *Glacier's* flying bridge. All birds in a quadrant from straight ahead to 90° off one side of the ship (the side where visibility was best) were identified to lowest taxon possible and were recorded as being in one of three 100-meter-wide zones out to 300 meters. Ship-following birds were identified as such and were counted only once, on the first transect during which they were seen in the quadrant being surveyed. Birds that were following the ship but did not enter the quadrant being surveyed were not counted.

On several occasions, additional observations were made from the ship's helicopters. The observer sat in the copilot's seat, looked ahead, and counted birds in a track approximately 150 meters wide while flying 90 miles per hour at 30–35 meters altitude. At this speed and altitude, penguins could be seen as they entered the water, and small groups could be counted accurately before they submerged.

Physical data taken on the first set of transects included half-hourly sea surface temperatures and salinities; in addition, expendable bathythermograph casts to 500 meters were made every half hour. During the second set of transects, sea surface temperature and salinity were measured hourly and expendable bathythermograph casts were made every 6 hours. The ship's crew obtained standard weather information every hour. Ice cover was recorded for each 10-meter transect, as was depth to bottom when conditions permitted.

Detailed presentation of the results must await thorough analysis of the data; at present only very tentative impressions can be presented. The results of the first series of transects indicated an increase in bird numbers from just offshore of the continental slope to about 50 kilometers shoreward of the shelf edge. Seaward of this region, bird sightings were relatively sparse, except in areas of pack ice near Scott Island. In the southern Ross Sea, few birds were seen away from Adélie penguin (*Pygoscelis adeliae*) rookeries or pack ice near the western shore. The increased bird densities in the vicinity of the front were manifested not as a sharp increase but rather as a broad band of moderately elevated numbers. The relationship of these elevated numbers to the front is not clear, since many of the birds seen were associated with the pack ice.

Two features of bird distribution off the Victoria Land coast are of particular interest. First, within the area of pack ice, bird densities varied; in some regions 6 to 11 birds per transect were common, while in superficially similar areas nearby, no birds were seen. Seal densities appeared higher in areas where birds were more abundant, but a correlation between these groups awaits statistical verification. Second, in transects perpendicular to the coast, bird numbers dropped off quickly once in open water outside the icepack. Birds were also less numerous in large leads between the icepack and the coast. Thus, for a considerable distance south of the shelf edge, the presence of pack ice seemed to be a more important predictor of bird numbers than did distance from the shelf edge.

On the voyage from the Ross Sea to Palmer Station, Anvers Island, the ship remained north of the ice pack in open water, but crossed what appeared to be relatively narrow bands of icebergs strung out in a north–south orientation. Birds also were encountered in patches, but the relationship of the patches of birds to either the presence of icebergs or other physical features was not obvious.

I thank the officers and crew of the USCGC *Glacier*, particularly Ensign C. Ridnaur and the marine technicians, for their support and help in numerous ways. The following helped with observations: Tony Amos, Erick Chiang, Murray Gregory, Peter Harper, David Harrowfield, Robert Kirk, Steve Morrell, Richard Reichle, Judy Sherburne, and J. Ward Testa. Peter Harper taught me much about the identification of tubenoses, and Tony Amos collected data on physical features between the Ross Sea and Anvers Island. The research was supported by National Science Foundation grant DPP 81-1939.

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Comparative studies of pygoscelid penguins in Admiralty Bay

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Our team of four arrived at the Polish Academy of Sciences' Arctowski Station, Point Thomas, King George Island, South Shetland Islands (62°10'S 58°30'W) on 6 October 1981. We departed in groups of two on 20 February and 21 March 1982. This year we collected data on breeding success, breeding synchrony, nest relief intervals and behaviors, diets, and the growth of chicks of sympatric Adélie (*Pygoscelis adeliae*), chinstrap (*P. antarctica*), and gentoo (*P. papua*) penguins.

A total of 800 Adélies, 300 chinstraps, and 400 gentoos reared 1.02, 0.97, and 0.90 chicks per pair, respectively, to creche age (3 + weeks). These data, combined with those we collected in 1977–78 (Trivelpiece 1981), indicate that the pygoscelid penguins did not differ with regard to breeding success. However, although Adélies were proficient at hatching eggs, especially in comparison with chinstraps, they were the least successful in rearing chicks.

For a study of breeding synchrony among the species, we determined the sex of and banded 200–300 pairs of each species and followed these pairs daily to obtain precise egg-laying dates. We found that the three species had very different incubation strategies. After clutch completion, Adélie males remained at the nest for an average of 12 days, after which the females took an incubation shift averaging 12 days. Chinstraps had shorter incubation shifts (about 5 days), and preliminary analyses indicate that females were as likely as males to take the first incubation shift. In contrast, gentoos did not fast during incubation, but relieved each other at about 24-hour intervals. During the chick phase, data on nests of each species were collected throughout all daylight hours for 5–8 consecutive days. Preliminary analyses of these data indicate that during this phase nest relief intervals were shorter than those previously reported.

Complete stomach samples were collected from 20 Adélie, 25 gentoo, and 20 chinstrap penguins that were feeding chicks. Diets of penguins in 1981–82 were similar to those we found in 1977–78 (Volkman, Presler, and Trivelpiece 1980). Adélie and chinstrap penguins ate krill almost exclusively; gentoos also ate mainly krill, but 15 percent of their diet was fish. Interestingly, in both years, male gentoos accounted for the majority of fish eaten by this species. These data suggest that all the pygoscelids except male gentoos rely heavily on krill as a food source during the breeding season.

We recorded the presence of 1-year-old chinstrap and gentoo penguins at Point Thomas: 4.9 and 7.8%, percent, respectively, of all chicks banded in 1980–81. This represents the first report that these species return to their natal rookeries as 1-year-olds; in contrast, Adélies do not return until 2–3 years of age.

Finally, we collected data on the growth of biomass, culmen, and tail retrix of 65 Adélie, 45 chinstrap, and 45 gentoo penguin chicks from hatching to fledging. Adélie and chinstrap chicks fledged at a mean age of 54 days, gentoo chicks at 74 days. Data from this study will be compared with similar data from 1977–78 to assess year-to-year variability in chick growth and to generate average growth curves for the pygoscelid penguins. Data on chick growth, breeding success, population numbers, diets, and nest relief intervals will be valuable in assessing any future impact on penguins of the commercial exploitation of krill.

We thank the Polish Academy of Sciences, Base Commander Lech Rosciszewski, and the personnel of Arctowski Station for their hospitality, friendship, and logistic support, all of which greatly benefited our research. We thank Colonels E. Morchio and R. Vergara, and all Fuerza Aerea de Chile personnel involved in our transportation to and from Antarctica. We also thank Captain P. Lenie and the crew of the R/V *Hero* for logistical support.

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Timing of egg formation in Adélie penguins

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All avian eggs are produced by similar physiological mechanisms: lipoproteins synthesized in the liver are deposited around a developing ovum while it is held in an ovarian follicle. When whole yolks are frozen, preserved, stained with potassium dichromate, and sliced, a pattern of light and dark yolk rings becomes apparent. These ring pairs correspond to night and day deposition of yolk, indicating a diurnal rhythmicity in yolk development. Layering is related to feeding cycles, but it is also present in fasting birds. The number of ring pairs and the rate of yolk deposition remain essentially the same for individuals within a species. This predictability in the timing of egg formation has led us to investigate how egg formation is integrated into the reproductive biology of a given species.

Adélie penguins arrive at the Cape Crozier rookery in late October after traveling across miles of Ross Sea ice. While still in open water, the penguins feed on euphausiids, which are rich in red-orange carotenoids, and thus deposit pigmented yolk which appears in rings of cross-sections. The transition from these "feeding" rings to "fasting" (creamy white and homogeneous) rings is conspicuous. Because carotenoids apparently are not stored in body fat, we consider this position in the yolk to mark the time when the penguins stopped feeding and began their sea ice trek.

Using methods developed by Grau (1976) and by Astheimer, Roudybush, and Grau (1980), we gave oral doses of a lipophilic dye (Sudan black B) to prelaying female penguins. The dye was deposited in developing yolk within a few hours of dosing, producing a blue ring in the yolk; this ring served as a date marker. The chronology of egg formation was determined by yolk-ring analysis in conjunction with arrival dates of individual penguins (see figure).

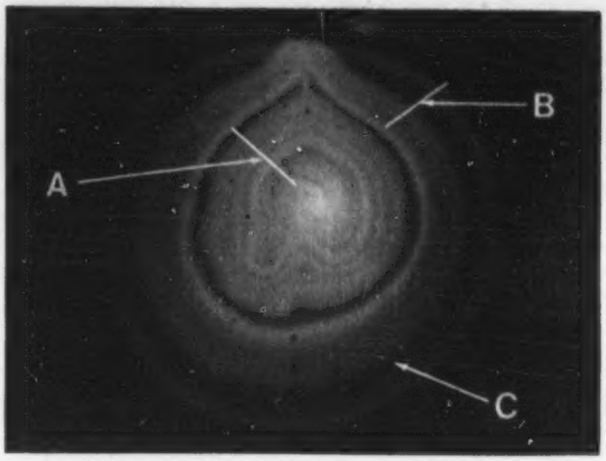
Two of us (Astheimer and Boekelheide) arrived at Cape Crozier on 30 October, and on 31 October and 1 November we captured and marked 60 penguins as they arrived at the rookery. Later we found 28 females of this group after they had paired. Oral doses of dye were given to these penguins and to an additional 132 mated females. Nest sites were identifed by stakes and dosed females were marked on their breasts with rhodamine dye.

Nests were checked daily; a total of 150 fresh eggs were collected, including 84 first, 54 second, and 12 third eggs. Third eggs are not common, but some females were induced to lay a third egg by removal of their first two eggs. No fourth eggs were laid, suggesting that only three follicles were actively developed.

Preliminary analysis of yolk rings shows a period of rapid yolk deposition of 14 to 16 days in all eggs regardless of order laid. This corroborates our data on egg composition, which indicates that, although total egg mass is less in second and third eggs, yolk mass within a clutch is essentially constant. An example of one typical clutch is given in the table. Our data suggest that yolk production is a deterministic process—possibly important for ensuring an adequate nutrient supply to the developing embryo.

Time-marking of yolk rings with Sudan black B dye proved exceptionally successful. At this point the following conclusions can be drawn:

- Yolk production is initiated while the females are still at sea. Therefore, proximal cues such as sea-ice breakup and food supply, as well as photoperiod, may stimulate the onset of rapid yolk deposition, which takes place over a period of 15 to 17 days.
- In 1981, yolk deposition in first eggs began 10 to 12 days prior to cessation of feeding, indicated by the clear change from carotenoid-pigmented to nonpigmented yolk. Second and third eggs were begun 3-4 and 6-8 days after the first. Hence, formation of all three yolks was begun long before the first egg was laid.



Central slice of an Adélie penguin egg yolk. A: yolk deposited during the feeding period; B: yolk deposited while fasting; C: a diffuse layer of Sudan black B dye. This slice was not treated with potassium dichromate, which greatly enhances ring definition despite seemingly homogeneous yolk.

- On the basis of the feeding-cessation yolk ring, we estimate that the time birds spent traveling across sea ice was 1 to 3 days.
- In all eggs, there is a 4–6-day lag between yolk completion and egg laying. This phenomenon is unknown in domestic species, which deposit albumen, membranes, and shell within 1 day of yolk completion. This lag period is typical of crested penguins (Grau 1982), emus (Hirsch and Grau 1981) and Cassin's auklets (Astheimer et al. 1980). In auklets, the yolk is held in the follicle (L. Astheimer unpublished data, University of California, Davis, 1982) and, as in other birds, fertilization of the ovum occurs after ovulation but before albumen deposition. The lag period may provide time for mobilization of amino acids for synthesis of albumen proteins, or of calcium for shell formation, or both. Or it may simply provide additional time to ensure that the female is successfully mated and thus may guarantee the high fertility that is common in wild birds. Ainley and LaResche (1973) noted that the peak arrival dates at Cape Crozier may vary by a week or more annually, depending on sea ice conditions. Thus, a female penguin, even if delayed in crossing the sea ice, could arrive at the colony with a

Composition of eggs in a typical clutch (nest 188)

Egg No.	Total mass(g)	Shell		Yolk		Albumen	
		Mass(g)	% of total mass	Mass(g)	% of total mass	Mass(g)	% of total mass
1	135.45	16.93	12.5	23.09	17.0	95.43	70.5
2	126.27	16.92	13.4	22.54	17.9	86.81	68.7
3	116.54	17.34	14.9	22.89	19.6	76.31	65.5

completed yolk in a follicle, and because of the lag period, still have 4 days for courtship and mating before laying her first egg. However, we have no evidence, that the lag period varies according to environmental conditions or behavior, or that it is restricted to species that begin yolk formation prior to the stimulation of mating behavior.

- The time between arrival and laying varied from 8 to 14 days, with a mean of 10.3 ± 1.55. When added to the sea ice sojourn of at least 1 day and the 3 to 4 days that elapsed between laying of the first and second eggs, the total time that females spent away from the sea in their initial visit to the colony was 13–22 days.

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Circadian rhythms in the body temperature of Adélie penguins

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Many behavioral, physiological, and biochemical characteristics of organisms are not constant in time, but rather exhibit pronounced variation. Variations that occur with a daily periodicity are called *circadian rhythms*. The term *circadian* is used because when there is no temporal information from the environment, the natural period of such rhythms normally is still approximately 24 hours. In nature, 24-hour environmental cues serve to reset the "biological clock." This process, known as entrainment, ensures that the period of these rhythms is exactly 24.0 hours, thereby permitting a constant phase relationship with solar time. The light-dark cycle experienced by an organism is one of the most potent synchronizers for circadian rhythms. In Antarctica, the natural lighting varies from continuous light during the austral summer to continuous darkness during the winter. This situation raises interesting questions regarding the 24-hour rhythms of organisms that live in these latitudes.

We examined the natural circadian rhythm of body temperature of Adélie penguins, *Pygoscelis adeliae*, during the austral summer of 1981–82. During the study there was no time of complete darkness, but there were some hours of twilight each night. The lighting intensity at these latitudes in January varies from greater than 50,000 lux during sunlight days to less than 1,000 lux during twilight (Gallardo and Piezzi 1973). Light intensity and quality during the study varied considerably during the day because of cloud cover.

Six Adélie penguins were captured in the vicinity of Palmer Station. Each bird was anesthetized with halothane, and a body temperature transmitter (AVM Instruments, Inc.) was implanted in its abdominal cavity. Lidocaine was used as a local anesthetic. After recovery, the penguins were confined in outdoor cages that were partially protected from the weather. Readings of body temperature were taken at half-hour intervals throughout the 5–10-day study period.

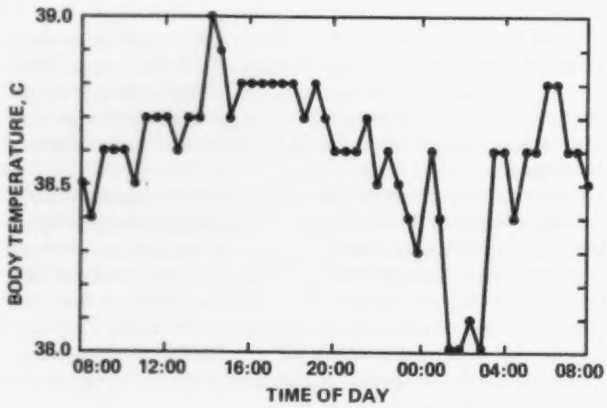

Figure 1. Rhythm in body temperature of a representative Adélie penguin. Each point is the average of data at each time for an 8-day period.

A representative body temperature rhythm of an Adélie penguin is shown in figure 1. The temperature values are averages of temperatures at identical times of day over 8 days. For this bird, the acrophase of the body temperature rhythm—that is, the high point of the cycle—occurred at 1400 hours. The acrophase for all the penguins was between 1400 and 1700 hours. The nadir, or low point, for each bird occurred approximately 12 hours later. The day-night temperature difference for all the birds averaged 1.0° ± 0.3°C.

To characterize the periodicity in the data, spectral analysis was used. The data were analyzed by a computer program that fits cosine functions to the raw data. Using a least squares technique, the periods with the maximum amplitude were de-

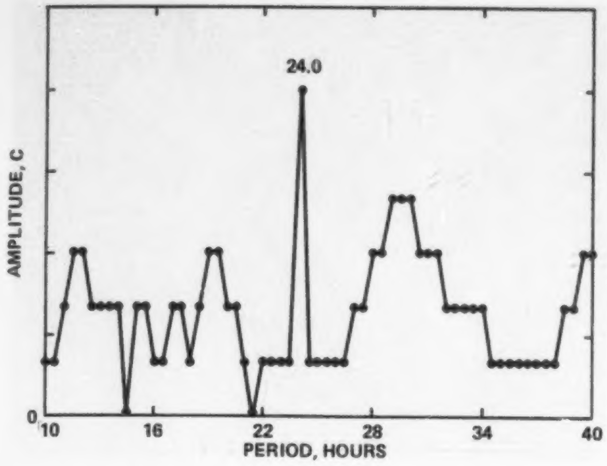

Figure 2. Spectral analysis of body temperature data within a range of 10 to 40 hours from an Adélie penguin.

termined (Sulzman in press). Figure 2 shows the results of period spectral analysis for the same bird as in figure 1.The amplitude periods we examined between 10 and 40 hours are plotted in half-hour increments. The major peak in this bird is at 24 hours. All birds examined had significant ($P > .001$) periodicity in the 24-hour range.

Adélie penguins clearly demonstrate a 24-hour rhythm in body temperature. Research also has established that these antarctic birds have at least one other rhythm and do not possess some others. For example, Derksen (1977) found that during the time Adélie penguins were incubating their eggs, there was a circadian rhythm of activity in the colony as a whole, though this rhythm was not evident in individual penguins. Another common diurnal rhythm found in birds, melatonin synthesis, could not be demonstrated in Adélie penguins (Benelbaz, Piezzi, and Lynch 1976). In a related species, the gentoo penguin (*P. papua*), serotinin levels in the pineal gland are higher at 2400 than at 1200 hours (Gallardo and Piezzi 1973). More studies on antarctic penguins are needed to establish with certainty the effects of the extreme photoperiods on the physiological circadian rhythms of these birds.

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Winter ecology of Weddell seals at White Island

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R. Davis, M. Davis, M Castellini, and M. Horning maintained a field camp at the northwest end of White Island during the 1981 austral winter (February through December). White Island is located about 25 kilometers southeast of McMurdo Station and is accessible by tracked vehicle throughout the year. The purpose of the study was to obtain information about the diving behavior of Weddell seals and their winter environment.

The camp consisted of two 5- × 6-meter huts, which served as living quarters, and a Jamesway garage, which housed the tracked vehicle (a Spryte) and two diesel electric generators (figure 1). An ice hole beneath one of the huts and penetrating 15 meters of ice was maintained throughout the winter. It was used for oceanographic measurements, biological sampling, and hydrophone recordings.

At every opportunity the field team made trips along the northern shore of White Island to deploy and recover time depth recorders and depth histogram recorders (Kooyman, Billups, and Farwell in press). The time depth recorders could record information for a 10-day period, and the depth histogram recorders, for a 25-day period. However, some recorders were not recovered for up to 7 months.

Five instruments were deployed and recovered during the early winter (late February to April); total time monitored was 67 days. Three mid-winter (June to August) records were obtained, covering 40 days. In addition, three records were ob-

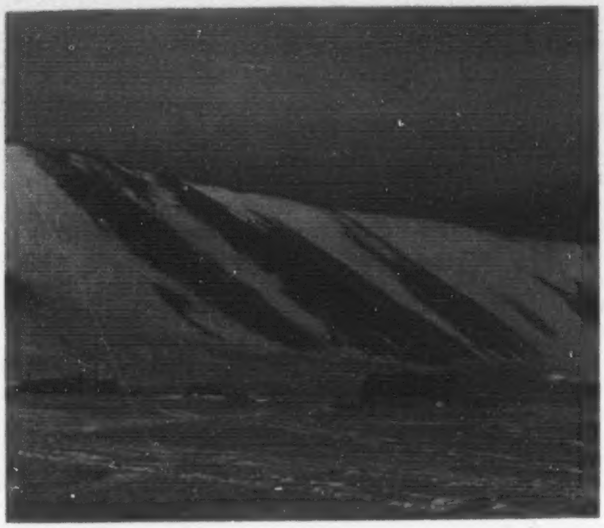

Figure 1. The field camp at White Island maintained from February through December 1981. The two fish huts were connected by a wooden vestibule and provided living and working quarters. The Jamesway garage housed a Spryte and two diesel generators. Fuel for the generators and for heating the camp was stored in two 1,900-liter squat tanks.

Figure 2. The view at 50 meters looking up at the tidal crack located at the west end of Big Razorback Island.

tained from McMurdo Sound in early August, covering 20 days. These recordings provided data on the preferred feeding depths of the seals.

As we were seeking seals on which to deploy or recover recorders, we carefully examined haul-out areas for feces. These formed the basis of a scatological study to determine the seals' preferred food. Both the diving depths and the otoliths recovered from the feces indicated that the major food was the antarctic smelt, *Pleuragramma antarcticum*.

We made hydrophone recordings routinely throughout the winter to estimate seal density and distribution. We made most of these recordings at the field camp, but we also made several at various locations along the coastline. The recordings along with sightings during the winter confirmed that the White Island population was resident throughout the year and did not migrate north during the winter.

Given the ice conditions, winter survival seemed a remarkable feat. The thinnest known ice was along the tidal crack, and even there it was 2 to 3 meters thick at the tidal crack between land and sea. Elsewhere, ice thicknesses in areas where seals were known to dive ranged to more than 100 meters. We conducted a detailed survey of ice movements and depth soundings along the northwest coast of the island. Where possible, we also observed under-ice conditions by scuba.

At both White Island and McMurdo Sound, we used a deep-submersible camera developed for this project to survey under-ice conditions as well as the bottom. We obtained under-ice photos down to a depth of 200 meters (figure 2) and bottom photos in a variety of areas ranging from depths just beyond the reach of scuba (40 meters) to the bottom of McMurdo Sound (540 meters).

These data are being used (1) to develop a comprehensive understanding of Weddell seal diving and feeding behavior under different seasonal and geographical conditions and (2) to define and describe, on an annual basis, the problem of under-ice orientation.

This research was supported by National Science Foundation grant DPP 81-09426.

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Reproductive ecology of crabeater and leopard seals along the Antarctic Peninsula

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If we are to conserve and manage efficiently the resources of the antarctic marine ecosystem, we must understand the interactions over time of the ecosystem's different components. Direct evidence of ecosystem relationships over time is difficult to obtain, but changes in the reproductive characteristics of species that consume krill might supply indirect evidence. This project is investigating whether changes in the reproductive status of selected antarctic seals might reflect changes in the availability of food in the marine community over time.

Fieldwork involving crabeater (*Lobodon carcinophagus*) and leopard seals (*Hydrurga leptonyx*) was conducted along the Antarctic Peninsula from December 1981 to March 1982. Access to seals was by skis over fast ice early in the season, and by Zodiac boats and Sikorsky HH-52 helicopters in pack ice after breakup of the ice This work had two phases and was principally concerned with collecting biological specimens for later analysis. The first phase was carried out at the British base, Faraday, from 8 December to 8 February. Reproductive and dental samples were collected from 300 crabeater and 20 leopard seals sacrificed by British personnel in the vicinity of the Argentine Islands (65°14'S 64°16'W) and Penola Strait (65°16'S 64°13'W). The second phase of the fieldwork was carried out from USCGC *Glacier* from 8 February to 17 March as it cruised Bransfield Strait (63°S 57°W), Gerlache Strait (64°41'S 62°14'W), and the vicinity of Seymour Island (64°11'S 56°37'W), James Ross Island (63°46'S 57°10'W), and South Shetland Island (62°30'S 58°W). Reproductive tracts and teeth were collected from 240 crabeater and 16 leopard seals sacrificed for this purpose. Stomach contents also were examined. Reproductive materials will be analyzed to provide information on the seasonal timing and age specificity of reproductive events. Teeth will be sectioned and used to determine age at death and age at sexual maturity.

Preliminary analysis of stomach contents confirmed that krill (*Euphausia superba*) is an important food for both crabeater and leopard seals (table). Crabeater seals and pygoscelid penguins also constitute a large portion of the leopard seals' diet. Some of the seals had ingested sand and rocks, in amounts varying from just a trace mixed with other prey to enough to fill the stomach; it is not immediately clear why they had ingested these items. I have no data on digestive rates and how they might affect the probability of encountering different items in the stomach. However, the high percentage of empty stomachs suggests that material passes rapidly through the digestive system.

Percent occurrence of food items in stomachs of crabeater and leopard seals along the Antarctic Peninsula, December 1981–March 1982

Stomach contents	Crabeater seals (n = 540)	Leopard seals (n = 36)
Empty	85 %	55%
Krill	8 %	17%
Krill, sand, rocks	4 %	0%
Sand, rocks	2 %	3%
Krill, sand, clam	0.2%	0%
Unidentified fish	0.2%	0%
Fish, krill, sand	0.2%	0%
Crabeater seal hair, blubber	0.0%	8%
Penguin feathers	0.0%	11%
Penguin feathers, sand	0.0%	3%
Contents not examined	0.4%	3%

Because the expression of reproductive characteristics in mammals is closely related to environmental factors (Sadleir 1969), changes in trophic and numerical relationships within the krill-based food web should be reflected in krill-consuming marine mammals. Marine mammals are especially useful in this regard because past events sometimes can be identified by calculating the age of individuals at the time of past reproductive events using teeth or bones. The mean age of sexual maturity of crabeater seals fell from approximately 4.5 years in the 1940's to 2.5 years in the late 1960's (Laws 1977) and then rose to approximately 4 years in the 1970's (Bengtson and Siniff 1981). This increased age of sexual maturity suggests that, with the slowdown of whaling in the late 1960's, the relative availability of krill in the ecosystem declined. This decline may have resulted from many factors, including numerical increases in krill-consuming populations, causing greater competition for food. The reproductive material obtained during the past field season should help clarify recent reproductive trends in antarctic seals, allowing a fuller understanding of interactions within the marine community.

The assistance of L. R. Airey, M. J. Baker, D. Burke, A. C. Morgan, P. D. Naylor, P. Salino, and other personnel at Faraday Base is gratefully acknowledged. I also thank D. Ragland and B. Weaver for spirited help in the field and laboratory; Coast Guard pilots C. Hessel, C. Shirk, J. Whitehouse, and J. Williams for talented helicopter support under difficult conditions; and the officers and crew of the USCGC *Glacier* for overall support of my program.

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Ultrasonic vocalizations of leopard seals *(Hydrurga leptonyx)*

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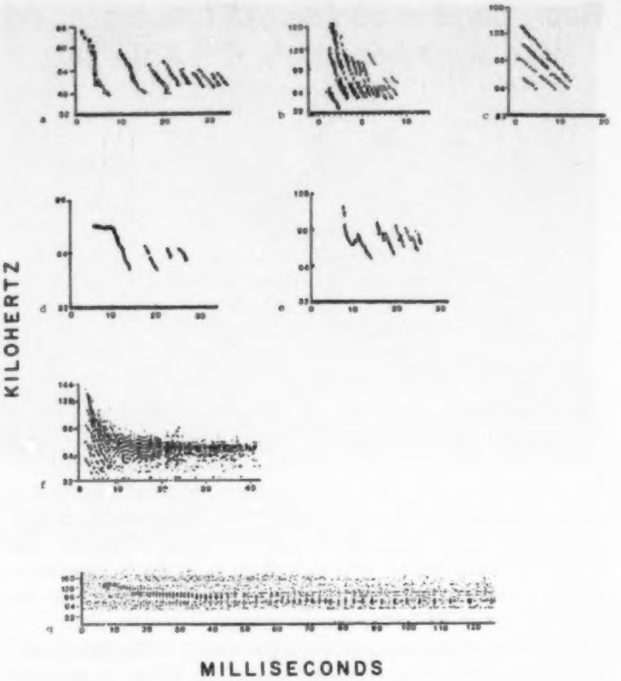
The vocal repertoire of leopard seals (*Hydrurga leptonyx*) has been studied in the wild by Stirling and Siniff (1979) and by Thomas and DeMaster (in press) using audio recording equipment. Using ultrasonic recording equipment, we conducted a series of studies on a captive leopard seal and found it capable of producing sounds of up to 164 kilohertz.

The leopard seal was a 4-year-old female, originally beached in Australia, that has been in captivity at Hubbs Sea World Research Institute since 1979. Live anchovies and striped bass were introduced into her tank, and her vocal activity in response to these prey was recorded. Recordings were made using a Racal Store-4 recorder and Bruel and Kjaer 8103 and 8104 hydrophones (system frequency response: 0.03 to 150 kilohertz for the 8104 and to 200 kilohertz for the 8103 ± 3.0 decibels). Since ultrasonic vocalizations tend to be directional, the two hydrophones were placed on opposite sides of the 5-meter-diameter tank.

The leopard seal responded to both species of fish by producing a variety of low-amplitude sounds. Frequency-modulated chirps, buzzes and frequency-modulated buzzes, and single clicks, double clicks, and click trains were recorded (see figure). Peak frequencies were extremely variable, ranging from 4 to 164 kilohertz. The amount of frequency variability that can be attributed to directionality is unknown. The most common peak frequencies were between 50 and 60 kilohertz. The highest frequency sounds were produced while the seal chased the smaller target (anchovies). The FM chirps swept as much as 60 kilohertz in 4 milliseconds and were only 4 to 10 milliseconds in duration.

Vocalizations of such extremely high frequencies have never been reported in pinnipeds, perhaps because researchers rarely have attempted recording at ultrasonic frequencies. These sounds are similar to the ultrasonic echolocation sounds that bats and dolphins use to find prey or to orient in their environment. Echolocation abilities in polar pinnipeds have been proposed by Poulter (1963, 1967) and Kooyman (1968) because it would help them find food or navigate during the dark austral winter. All efforts to demonstrate this ability in pinnipeds experimentally have been unsuccessful (Evans and Haugen 1963; Schusterman 1966; Scronce and Ridgway 1980), but none of the species studied are known to vocalize ultrasonically. We cannot say yet if leopard seals produce these sounds routinely during prey pursuit or if the sounds are merely a short-term response to a novel situation.



Ultrasonic sounds produced by a leopard seal. a–e: frequency-modulated chirps; f: frequency-modulated buzz; and g: click train.

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Melt pools as natural experimental arenas for acoustical studies

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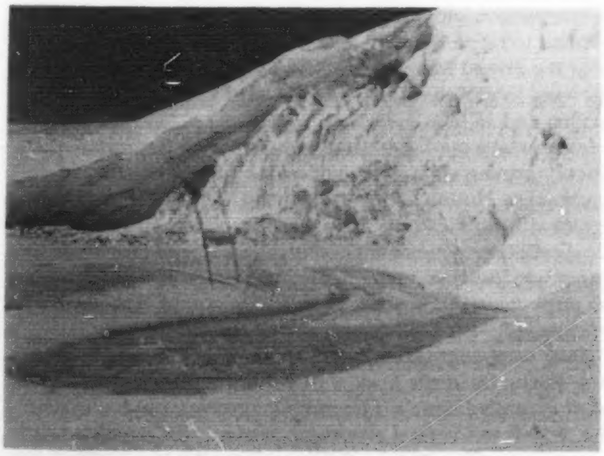
Research on the acoustic behavior of whales and pinnipeds should combine studies of captive animals with studies of the natural acoustic behavior of wild subjects. Captive studies allow quantitative evaluation of the acoustic abilities of individuals of known age and sex under controlled conditions. This approach has been used with several marine mammal species (Busnel and Fish 1980; Caldwell and Caldwell 1971; Terhune and Ronald 1972). However, many marine mammals, including Weddell seals, cannot be studied in captivity because of logistical or husbandry problems.

Many marine mammals decrease vocal activity in captivity because of reverberation in their tanks, lack of environmental stimulation, changes in feeding behavior, or artificial social structures. Recent evidence (Norris personal communication) suggests that common dolphins (*Delphinus delphis*) changed the duration of their whistles in captivity because of tank reverberation. Echolocating Atlantic bottlenose porpoises (*Tursiops truncatus*) shift the frequency of their pulses to optimize the signal-to-noise ratio in captivity (Au and Hammer 1978). Reverberation in captive enclosures also may cause marine mammals to change temporal and amplitude characteristics of their vocalizations. *T. truncatus* vary the repetition rate of echolocation pulses as a direct function of the ambient level in captivity (Au, Penner, and Kadane 1982). For Weddell seals, which produce vocalizations as high as 193 decibels per 1 micropascal (Thomas and Kuechle in press), normal-amplitude sounds would be overpowering in captivity.



Melt pool at Hutton Cliffs in 1979.

In the Antarctic, melt pools form in the fast ice because of sunlight reflecting off nearby land and melting of the surface ice (figure). Traditional melt pool sites in McMurdo Sound are located at Hutton Cliffs, Turtle Rock, Inaccessible Island, Tent Island, and Turks Head. They form in early November and remain stable until the sea ice breaks up. As the pool forms, the surface water melts and eventually the bottom of the pool opens into sea water. Because Weddell seals commonly use these pools, we attempted to determine the pools' potential as an experimental arena for acoustical research.

In 1977 we conducted a series of playback studies and projected Weddell seal vocalizations into the pool while monitoring vocal responses with a hydrophone and observing behavioral responses from the edge of the pool. Under other circumstances it is difficult to observe under water behavior of Weddell seals. Most of the seals were tagged, and thus we knew their age and sex. They readily responded vocally to playbacks. In one case, highly aggressive behavior was observed: a male attacked another seal in the pool, believing the sounds were from that seal.

The pool provided an excellent acoustical chamber. Thick sea ice between the pool and the water prevented transmission of vocalizations from seals in the sea to the pool. The irregular shape of the pool walls and the absorbent characteristics of the slushy ice on the walls and surface prevented reverberation of the seals' vocalizations. In addition, because wind and wave noise were absent, background noise was minimal, thus improving the signal-to-noise ratio of vocal responses. This playback study provided excellent results on the responses of Weddell seals to conspecific vocalizations (Thomas, Zinnel, and Ferm in preparation).

In 1979, we attempted to investigate the vocal behavior of Weddell seals with impaired vision by temporarily attaching blindfolds and chasing them into a melt pool. Using a hydrophone and a tape recorder, we listened for vocalizations from these seals. Unfortunately, the blindfolds soon became detached and no vocalizations were detected over the 5-minute period.

Melt pools provide an excellent experimental acoustic arena with no chance of escape or harm to the seals. Many other perceptual and acoustic studies could be attempted because the location of melt pools is predictable, although size varies, and they generally last for the 2-month breeding season of antarctic pinnipeds.

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Weddell seal population dynamics and antarctic cod movement patterns in McMurdo Sound

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The purpose of our fieldwork during the 1981–82 season was to observe the movement patterns of the antarctic cod *(Dissostichus mawsoni)* and the distribution and abundance of Weddell seals *(Leptonychotes weddelli)* in McMurdo Sound. Fieldwork commenced with the arrival of two scientists at McMurdo Station on 9 October 1981 and a third on 19 October. Ultrasonic transmitters were surgically implanted in seven antarctic cod. The fish's movements offshore from McMurdo were followed by means of an automatic locating system consisting of a three-hydrophone array (Thomas et al. 1980). Portable directional hydrophones were used to locate fish when they moved beyond the range of the automatic locating system. This work confirmed our earlier observations that the fish appeared to move slowly with the current, toward the Ross Ice Shelf. One fish, tagged with a depth sensing transmitter, moved down in the water column at a rate of 22 meters per minute until it leveled off at a depth of 500 meters.

To observe the reaction of Weddell seals to a live antarctic cod, a cod was tethered on 20 meters of line below a seal breathing hole at Hutton Cliffs and was observed with underwater television. In previous experiments, frozen specimens had elicited no response. This time, however, there was an immediate reaction. As soon as the fish was released, several seals chased it until it was captured and then virtually shook the fish apart under water. One seal attempted to haul the remains up onto the ice but was unsuccessful; it may have been inhibited by the presence of the researchers photographing the event.

A cooperative effort continued with Art DeVries and Joe Eastman to collect, compile, and analyze natural history data from the antarctic cod fishing operations over the past 10 years. Preliminary analyses document a statistically significant increase in cod abundance during October and mid-November. Although fishing success varied a great deal, researchers caught cod at a relatively constant rate with varying amounts of effort. Other parameters that will be analyzed for the antarctic cod include depth preference, size by depth, activity pattern, relative annual abundance, sex ratio, and length-weight relationships.

Our work with Weddell seals during the 1981–82 season included six censuses of seals in eastern McMurdo Sound, from Scott Base to Cape Evans, conducted from tracked vehicles during mid-November and early December. Each seal was checked for age (adult, sub adult, or pup), sex, and presence or absence of a tag. Census data currently are being compiled, and Jolly-Seber estimates of population size and other parameters will be determined. These 1981 data are being added to the long-term population database for the Weddell seals of McMurdo Sound. Early-season work emphasized tagging adult males and retagging individuals that had lost one tag. Later, pups were tagged at or just after weaning. In an attempt to solve the problem of high tag loss from pups, common in previous studies, expandable "bracelet" tags were applied to pups. However, it appears that the bracelets will need modification, since tag loss continues to be a problem.

One helicopter census was conducted on 17 November 1981. In comparison with previous seasons, a greater number of pups seemed to be on the west side of McMurdo Sound, especially near the Strand Moraines and Blue Glacier. The seal count on the west side of the sound was 194 adults with pups, 304 lone adults, and 16 lone pups.

There was a marked shift in pupping away from some traditional pupping sites. Most noticeable was a reduction in pup numbers at Hutton Cliffs and South Hutton Cliffs and an increase at Turks Head. We do not know the reason for this shift; ice conditions were not noticeably different, and human disturbance was less than in many previous years. The total number of pups over the eastern side of the sound was relatively unchanged.

Tests were conducted with a 250-milliwatt remote transmitting station on Turtle Rock, a prototype of stations that will be used to receive signals from radio-tagged seals and to transmit the signals to a central processing station. The signal strength was monitored at various distances from the transmitting station. In general, the signal level varied as predicted by radio propagation range equations except when the signal was shadowed by a land mass. Thus, any receiving antennas at McMurdo Station must be placed high enough to be within sight of the transmitting stations.

The more remote areas of McMurdo Sound and the Ross Sea were surveyed for tagged Weddell seals from the USCGC *Glacier* in early January. Strip censuses of seals in pack ice also were conducted in transit, as were surveys in fast ice areas along the northern Victoria Land coast. Special attention was paid to the pack ice surrounding Franklin and Beaufort Islands and to the north of Ross Island, because these areas were expected to have tagged immature seals from Erebus Bay. We found more adult-size Weddell seals than expected but no tagged seals until we approached Ross Island.

We used helicopter support to document the postpupping distribution of Weddell seals in the remaining fast ice areas of McMurdo Sound and to continue our search for tagged seals. Adult seals on both sides of the sound had moved into the area adjacent to the permanent ice shelf, while many immature seals had moved into the Erebus Bay region vacated by the adults. A considerable number of tagged yearlings were found in these surveys that had not been sighted earlier in the season. Approximately 40 seals with known history were radio-equipped and followed until mid-February. All of these remained in the Erebus Bay region or were not sighted again. Tagged adult seals from previous years were found in low numbers on the western side of McMurdo Sound as far north as Granite Harbor.

Reproductive tracts and lower jaws were collected from the Scott Base seal kill. Observations of stomach contents were made on 32 females and 20 males. Pregnancy rate in 27 adult females was 85 percent. Laboratory analysis of ovaries and aging of teeth will be done at the University of Minnesota.

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Trophodynamics of mesopelagic micronekton in the southern ocean

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During the austral summer of 1982, a program was initiated to investigate the trophodynamics and ecology of micronekton in the major ecosystems of the southern ocean. Initial sampling with opening/closing midwater trawls was conducted from the R/V *Hero* (9–17 February 1982) in two of the deep basins (less than 1,000 meters) of the Gerlache and Bransfield Straits. Most of the collecting was focused in Croker Passage (64°06'S 61°53'W) adjacent to Brabant Island. Predictably, trawl samples revealed communities with relatively few species, yet high abundance, of micronekton. The dominant fish species were the nototheneid *Pleuragramma antarcticum* and the myctophid *Electrona antarctica;* other important fish species included *Gymnoscopelus nicholsi, Protomyctophum bolini, Electrona carlsbergi* and *Lampanyctus achirus.* Less common fishes included *Cyclothone* sp., *Bathylagus antarcticus,* and an as yet unidentified paralepidid.

Discrete-depth hauls revealed that the upper 50 meters of the water column were overwhelmingly dominated by dense patches of krill, *Euphausia superba.* The deepest layers of the basins were characterized by large gammarid amphipods (e.g., *Eurythenes, Cyphocaris, Eusirus)* and a large population of the mysid *Antarctomysis.* Diel vertical migrations do not appear to be a prominent feature of the feeding patterns of the mesopelagic fish fauna, no doubt because of the disproportionately long periods of daylight during the austral summer. Fish feeding patterns clearly are linked to the populations of *E. superba,* which is a major dietary item for most of the fish species examined. Preliminary stomach content analyses, however, indicate that these fishes prey on a number of the region's zooplankton, including amphipods, chaetognaths, copepods, and ostracods. Detailed stomach content surveys for identification of prey items and chemical analyses of daily rations are in progress in our respective laboratories.

Preliminary data on the age patterns of the mesopelagic fish fauna suggest that the antarctic forms are much longer-lived than their taxonomic and ecological counterparts from subtropical and tropical waters. Correlative growth data from otoliths and chemical composition analyses are accumulating but as yet are too few for interpretation.

The final results of our first year's efforts will be a preliminary characterization of the basin's micronektonic fauna in terms of their relative abundance, nutrient uptake patterns, and age and growth. These data will be compared with additional data collected in 1982–83 from the basins and from offshore.

In the coming year, additional sampling of these basins is planned to better define patterns of vertical distribution. Comparative sampling in more open waters of the Ross Sea will be initiated from the icebreaker *Glacier.*

This research was supported by National Science Foundation grants DPP 81-07510 to T. L. Hopkins and DPP 81-19621 to B. H. Robison. Field personnel included the authors and T. M. Lancraft.

Terrestrial biology

In situ carbon metabolism by the cryptoendolithic microbial community in the antarctic cold desert

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The ability of the cryptoendolithic microbial community to actively metabolize organic and inorganic carbon sources was studied *in situ* at Linnaeus Terrace (77°36'S 161°05'E; 1,650 meters in altitude) in the Asgard Range, southern Victoria Land. Previous studies (recently reviewed by Friedmann 1982) have shown that this community includes algae and fungi (which form a lichen association), as well as bacteria. The lichen algae (phycobionts) are the primary providers of organic nutrients for the fungi and bacteria in this simple ecosystem. Our purpose is to investigate carbon metabolism of this cryptoendolithic community under the environmental extremes of the antarctic cold desert.

Portions of large, flat rocks colonized by cryptoendolithic lichens were soaked with various carbon-14 (^{14}C)-labeled organic (acetate, glucose, and glutamate) and inorganic (bicarbonate) carbon sources at micromole concentrations. After incubation under ambient conditions, the rocks were transported to the Eklund Biological Laboratory at McMurdo Station, where the soaked portions were removed and crushed to sand. The ^{14}C-labeled lipids were extracted with chloroform and methanol according to the procedures of Bligh and Dyer (1959) as modified by White and others (1977). The lipid extract also was used to determine the active biomass expressed in lipid phosphate (White et al. 1979). As shown in table 1, incorporation of organic compounds increased with time and was not affected by darkness. This represents the active metabolism of heterotrophs (fungi and nonphotosynthetic bacteria) in the community. When ^{14}C-bicarbonate was added to the rock surface and allowed to soak into the lichen zone, incorporation increased with time and was light dependent. There was some bicarbonate incorporation in the aluminum foil-covered "dark" control rock, suggesting incorporation by a heterotrophic microbial population. Similar results were obtained in other experiments (not reported here) with crushed rock samples under controlled light and temperature conditions.

Our experiments suggest that the cryptoendolithic microbial community actively metabolizes dissolved carbon compounds. Friedmann (1978) had previously shown that melting snow is the source of water for cryptoendolithic lichens, and it seems reasonable to postulate that bicarbonates dissolved in snowmelt are used by the organisms.

To study the uptake of gaseous carbon dioxide (CO_2), inverted glass jars were attached to lichen-colonized rocks and $^{14}CO_2$ was produced by acidifying ^{14}C-bicarbonate in the closed jars. The rocks were incubated *in situ* and then transported to the Eklund Biological Laboratory for analysis of ^{14}C-incorporation and for biomass determination. Results are shown in table 2. No measurable incorporation was found after 7 days under ambient conditions. After 2 weeks, CO_2 incorporation into cellular lipids could be demonstrated, both in dry rocks and in rocks soaked with CO_2-free water prior to incubation. The fact that there was appreciably more incorporation into the "dark" control further suggests nonphotosynthetic CO_2 fixation. The amounts of biomass in the samples were in the same order of magnitude, and the variation probably reflects the difference in thickness of the lichen zone in rocks (Friedmann 1982).

Field personnel during the 1981–82 season included E. Imre Friedmann, Mason E. Hale, Jr., Christopher P. McKay, Stephen A. Norton, and J. Robie Vestal. This research was supported by National Science Foundation grant DPP 80-17581 to E. I. Friedmann.

Table 1. Incorporation of ^{14}C-labeled carbon sources into lipids of the cryptoendolithic microbial community *in situ* at Linnaeus Terrace, Asgard Range (incubation period 5 or 14 days, from 25 November 1981)

Carbon source	5 days	14 days	14 days (dark[a])
^{14}C-acetate	943[b]	1,504	1,546
^{14}C-glutamate	562	1,527	N.D.[c]
^{14}C-glucose	948	945	1,096
^{14}C-bicarbonate	437	1,085	462

[a] Dark = rock covered with aluminum foil.

[b] Figures indicate disintegrations per minute per micromole of lipid phosphate.

[c] N.D. = not determined.

Table 2. Incorporation of $^{14}CO_2$ into lipids incubated *in situ* at Linnaeus Terrace, Asgard Range, and biomass in respective rock samples expressed in lipid phosphate (incubation period 7, 14, or 16 days, from 25 November 1981)

	7 days (dry rock)	14 days (wet[a] rock)	16 days (dry rock)	16 days (dark,[b] dry rock)
Incorporation (disintegration per minute per micromole lipid phosphate)	N.D.[c]	647 ± 117[d]	395 ± 126	653 ± 163
Biomass (micromole lipid phosphate per square centimeter)	0.110 ± 0.01[d]	0.060 ± 0.004	0.068 ± 0.02	0.050 ± 0.006

[a] Wet = soaked with CO_2-free water prior to incubation.

[b] Dark = glass jars were covered with aluminum foil.

[c] N.D. = none detected (i.e., counts were not above 2 times background).

[d] Mean ± *SD* (n = 3).

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Physiological adaptations of biota in antarctic oasis lakes

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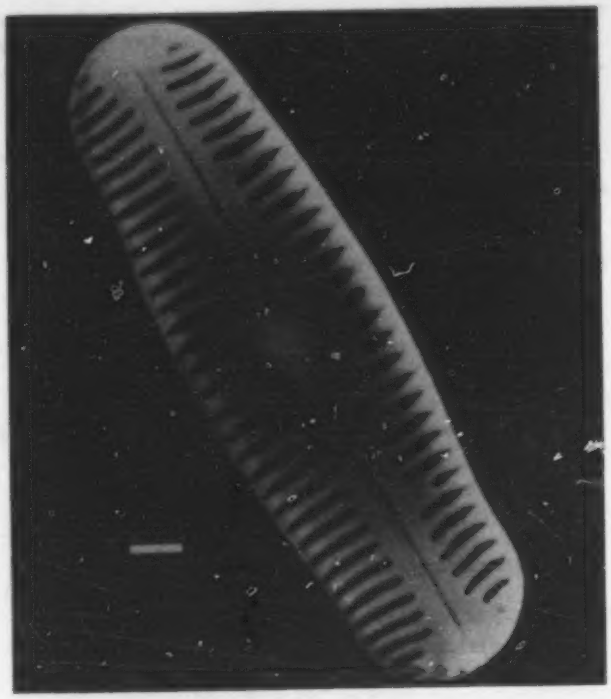
Our research seeks to identify and characterize the extent to which southern Victoria Land lake communities, species, or strains are physiologically adapted for survival and growth under certain environmental extremes. Field studies during the 1980–81 and 1981–82 austral summers at Lakes Bonney, Fryxell, Hoare (Taylor Valley), and Vanda (Wright Valley) have addressed adaptions to (1) low light, (2) low temperature, (3) hypersalinity, (4) supersaturated oxygen, (5) nutrient limitations (e.g., nitrogen, phosphorus), (6) lack of turbulence, and (7) desiccation or freeze-thaw cycles. We list here only new information on adaptations to variables 1–4 above and discuss briefly the unique stromatolites and endemic algal species. For additional information, see Allnutt and others (1981), Cathey and others (1981, in press), Kaspar and others (in press), Love, Simmons, Wharton, and Parker (in press), Love, Simmons, Wharton, and Parker (in press), Parker and others (1980, 1982, in press), Parker and Simmons (1981), Seaburg, Parker, and Simmons (1981), Simmons and others (1981), Wharton (1982), and Wharton and others (1982).

Adaptations to low light. The perennial 3–6-meter-thick, rock- and soil-strewn ice covers of the four lakes vary in their average surface light transmittance (as percent) and average extinction coefficients (E_{PAR}) for photosynthetically available radiation (PAR) of 400–700-nanometer wavelength range for their underlying waters: Bonney, percent, 0.157 E_{PAR}; Hoare, 1.7 percent, 0.183 E_{PAR}; Fryxell, 1.5 percent, 0.733 E_{PAR}; and Vanda, 18.6 percent, 0.055 E_{PAR}. Unialgal clonal cultures of *Phormidium frigidum* Fritsch, the dominant bluegreen alga in all benthic mats, grows in the laboratory with about 0.2 microeinstein per square meter per second of continuous cool white fluorescent light, corresponding closely with PAR values near the maximum depth of algal mats in the lakes (Parker et al. 1980). This supports earlier suggestions that this alga can quantitatively adjust its photosynthetic pigments or chromatically adapt to low light levels (Simmons et al. 1981; Wharton 1982). A clonal isolate of a moss recently discovered in deep-water benthic algal mats of Lake Vanda grows with approximately 2.0 microeinstein per square meter per second of continuous cool white fluorescent light. These findings suggest greater adaptation to low light or lower compensation point intensities than many photosynthetic aquatic organisms. The lowest compensation point levels determined for a Signy Island lake *Phormidium* sp. was 4.1 microeinstein per square meter per second, and for the aquatic moss *Drapanocladus*, 5.0 microeinstein per square meter per second (Priddle 1980a, 1980b).

Adaptations to low temperature. Seaburg and others (1981) have provided the only definitive treatment on the temperature-growth physiological ecology of algae from antarctic lakes. Of 35 algal taxa (128 clonal cultures) from southern Victoria Land, a large proportion were facultatively, and a smaller number obligately, cold adapted. The latter group, the true psychrophiles which grew at less than 20°C, usually with optima of 10°–12°C, came primarily from stable low-temperature lake environments rather than from soils, ephemeral meltstreams, and moat-water habitats. No antarctic algal isolate grew at above 30°C. A parallel study of algal isolates from Virginia habitats revealed no obligately cold-adapted strains, regardless of whether isolates came from winter or summer algal communities. However, more cold-tolerant isolates came from winter communities, and a number of isolates grew at 34°C (K. G. Seaburg and B. C. Parker unpublished data, Virginia Polytechnic Institute and State University 1982). Thus, the degree of cold-temperature adaptation for antarctic algae, especially lake algae, is significantly greater than for temperature strains. These findings are further supported by experiments involving incubation of algal communities from the oasis lakes at 2°, 12°, and 25°C. Carbon-14 (^{14}C)–bicarbonate primary productivity and hydrogen-3 (^{3}H)–organic uptake rates were highest at 12° and strongly inhibited at 25°C. Bacterial isolates also appear cold-temperature adapted.

Adaptations to hypersalinity. Whereas Lake Hoare is entirely fresh, Lakes Fryxell, Bonney, and Vanda have highly saline waters at greater depths. Planktonic green flagellates and several diatoms now have been isolated into unialgal and/or axenic culture from Lake Bonney and are salt-tolerant (e.g., *Navicula shackeltoni*, a new *Nitzchia* species) or salt-requiring (e.g., *Pinnularia cymatopleura*, figure; a new *Navicula* species). Of special interest is the fact that our salt-tolerant and salt-requiring diatom isolates are also obligate cold-temperature strains (i.e., psychrophiles), with growth optima at about 10°–12°C. These are the first axenic diatom isolates with both physiological adaptations, and their importance as experimental tools should be obvious.

Adaptations to supersaturated oxygen. A rare environmental extreme is perennial oxygen (O_2) supersaturation, which occurs in the shallower waters beneath the perennial ice covers of these oasis lakes. Two important adaptions to this supersaturated O_2 concern (1) the effect on photosynthesis vs. photorespiration and (2) oxygen toxicity to bacteria. We have suggested that the high percentages of extracellular organic products detected in antarctic lake plankton ^{14}C primary productivity studies result from stimulated photorespiratory activity (inhibited photosynthesis) with excretion of organic products by the algae (Parker and Simmons 1981). Presumably, the enzyme Ribulose-bisphosphate carboxylase-oxygenase, which can use both carbon dioxide (CO_2) (carboxylase) and O_2 (oxygenase) as substrates, under conditions of high O_2 and low CO_2, functions primarily as an oxygenase in photorespiration. Thus, extracellular products such as glycollate, glyoxylate, or certain amino acids are produced in large quantities relative to cellular organic carbon. Supporting this suggestion are field studies showing that the greater percentages of extracellular organic products in primary productivity experiments occur in the shallower, more highly oxygenated depths of Lakes Fryxell, Hoare, and Vanda.



Scanning electron micrography of *Pinnularia* cf. *cymatopleura* an axenic halophilic and psychrophilic diatom isolate from the cold, saline benthos of Lake Bonney. Bar = 1 micrometer.

Nonphotosynthetic bacteria are the most abundant heterotrophs in the plankton and benthic algal mats, whether detected by viable spread-plate counts or by direct fluorochrome staining. We have found that while bacteria in the mats may be inhibited by supersaturated O_2 conditions, many in the plankton are resistant to or stimulated by supersatured O_2. Three O_2-stimulated bacterioplankton isolates produce about three times the superoxide dismutase (SOD) activity after short-term incubation, indicating that these isolates have an inducible enzyme (E. M. Gregory unpublished data, Virginia Polytechnic Institute and State University 1982).

Modern stromatolites—Adaptations to nonturbulence and metazoan absence. Most of the benthic mats of the oasis lakes are being preserved as ". . . organosedimentary structures produced by sediment trapping, binding, and/or precipitation resulting from metabolic activity and growth of organisms, primarily bluegreen algae" (Awramik, Margulis, and Barghoorn 1976, p. 149), and hence are stromatolites. Diatoms and bacteria also occur in most mat types presently known from Lakes Bonney, Chad, Fryxell, Hoare, and Vanda. These stromatolites represent the highest latitude (>77°S) and only known Recent, cold stromatolites on Earth and, as such, may represent reasonable analogs of the more abundant Precambrian stromatolites. Consequently, they can serve as models for interpreting the development, diagenesis, and paleoecology of ancient stromatolites (Love, Simmons, Parker, and Wharton in press; Parker et al. 1981; Wharton 1982; Wharton et al. 1982).

Metabolic activity of the antarctic stromatolite mats results in calcite precipitation, especially under higher alkalinity conditions (Wharton et al. 1982), and probably other minerals biogenically form (Parker et al 1982). Metabolism and growth of these organisms are influenced by light, temperature, salinity, O_2/CO_2, nutrient levels, turbulence, or mixing, all of which are under investigation. Organic matter is also well preserved and includes keragen (i.e., organic matter insoluble in organic solvents) and geolipid (i.e., organic matter soluble in organic solvents, e.g., chloroform), the amounts and components of which are currently under investigation.

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Physiological adaptations of antarctic terrestrial arthropods

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In 1981, investigations of the adaptation of terrestrial arthropods to low temperatures in the maritime Antarctic were expanded to include seasonal monitoring throughout the year at Palmer Station (64°46'S 64°03'W). During the austral summer these species use one of two survival mechanisms, freeze tolerance or freeze avoidance (Lee and Baust 1981). The supercooling point (SCP) refers to the temperature at which spontaneous freezing of body water occurs. For species susceptible to freezing, it represents the lower survival limit.

Freeze-tolerant larvae of the chironomid *Belgica antarctica* maintained their SCP's at relatively high levels throughout the year (table). Winter-acclimatized larvae were freeze-tolerant to −15°C. This level of tolerance is similar to that of larvae collected during the summer, indicating that cold-hardiness is retained throughout the year (Lee and Baust 1981). Alternatively, freeze-susceptible species avoid freezing by the selection of thermally buffered hibernacula and seasonal depression of the SCP. *Alaskozetes antarcticus* and *Cryptopygus antarcticus* demonstrated enhanced supercooling capacity through February and March, reaching and maintaining SCP's of between −20° and −30°C during the winter (table). Within the overwintering microhabitat of these species, an SCP of −10° to −15°C should be sufficient to protect tissue from freezing at any time of the year (Baust 1980). High-performance liquid chromatographic analysis of seasonal cryoprotectant levels for each species are in progress (Baust and Edwards 1979).

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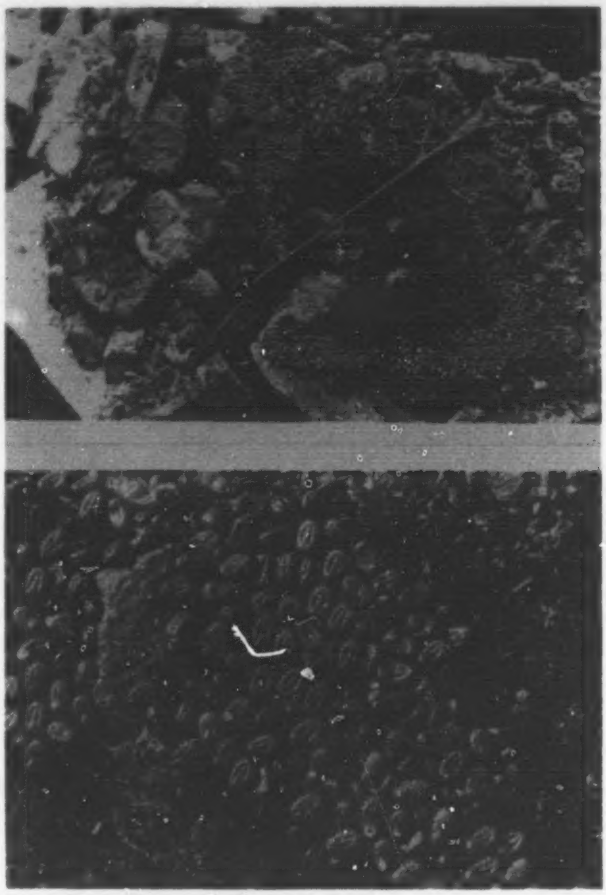
Large colonies (numbering 1,000 or more individuals) of the seabird tick *Ixodes uriae* were located on the periphery of Adélie penguin rookeries (figure). Aggregations composed of all life stages were found beneath large rocks in well-drained sites. At Palmer Station this species apparently requires a minimum of 3 years to reach maturity, overwintering successively as an egg, an engorged larvae, and an engorged nymph. Newly laid eggs had the greatest supercooling capacity (−29°C), followed by larvae and nymphs, which freeze at between −15° and −20°C. This species is freezing-intolerant. Engorged nymphs did not accumulate cryoprotectants (i.e., glycerol, sorbitol, or trehalose) during the winter. Chill coma temperatures ranged between −1.5° and −5.0°C for adults and nymphs. Desiccation stress had no effect on SCP values or glycerol levels in engorged nymphs.

The elevation of basal metabolic rates in polar ectotherms as compared with temperate or tropical forms is termed metabolic cold adaptation. Block and Young (1978) reported elevated respiration rates in antarctic mites. Our studies of oxygen consumption in *B. antarctica* and *I. uriae* revealed no evidence of metabolic cold adaptation in these species; however, the activation energies exhibited by the chironomid larvae indicate that metabolic rate is relatively independent of temperature as compared with temperate species (Lee and Baust 1982). Compensatory acclimation refers to changes in the rate of metabolic processes in response to altered environmental conditions. Acclimation to 0° or 10°C for 1–2 weeks had no differential effect on respiration rates in either species. These results suggest that *B. antarctica* and *I. uriae* lack the capacity for compensatory acclimation of respiration rate.

Most polar terrestrial arthropods tolerate temperatures greater than +20°C for only a few hours. Females of *I. uriae*, however, tolerated exposure to +40°C. This limit agrees closely with the thermal environment experienced during the ectoparasitic portion of their life cycle.



Top: Aggregation of *Ixodes uriae* on the periphery of an Adélie penguin rookery. Spatula is 22 centimeters long. Bottom: Close-up of aggregation composed primarily of engorged nymphs.

This research was supported by National Science Foundation grant DPP 78-21116. The field team included Richard E. Lee, Jr. (December–March 1981), Dave Johnson, and Bob Watkins (December 1980–December 1981).

Seasonal supercooling points for terrestrial arthropods at Palmer Station, 1981 (mean °C ± standard error; n = 10–20)

Species	Jan	Feb	Mar	May	July	Sept	Dec
Belgica antarctica (larvae)	− 5.7 ± 0.2	− 5.8 ± 0.3	− 6.5 ± 0.4	− 7.3 ± 1.1	− 8.0 ± 0.9	−11.5 ± 1.3	− 7.0 ± 0.4
Cryptopygus antarcticus	−13.5 ± 1.9	−19.3 1.4	−20.7 ± 1.8	−25.4 ± 0.6	−28.5 ± 0.5	−25.4 ± 0.8	−25.8 ± 0.3
Alaskozetes antarcticus	−11.1 + 1.5	−20.5 1.5	−23.5 ± 2.0	−30.8 0.4	−28.8 ± 1.1	−25.2 ± 1.0.	−14.9 ± 2.2
Ixodes uriae (nymphs)	−11.5 ± 1.9	−20.2 ± 0.6	−18.7 ± 1.6	−16.0 ± 0.7	−15.1 ± 2.6	—[a]	−20.2 ± 0.9

[a] Data not collected.

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Medical research

Environmental survival of human respiratory viruses at South Pole Station

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Midwinter episodes of respiratory tract illnesses (RTI) occurred among 22 healthy human adult subjects socially isolated at South Pole Station for 8½ months during 1978. These episodes occurred 10 and 27 weeks after station closing, long after the incubation period of known human respiratory viruses and at a time when the introduction of new virus to the community was impossible. Virologic and serologic data identified parainfluenza virus types 1 and 3 as agents etiologic in these RTI episodes (Muchmore et al. 1981). Human parainfluenza viruses cause mild to moderate RTI of short duration in healthy human adults, with virus shedding usually lasting 4–7 days. The reappearance of parainfluenza virus infections within this community after 10 weeks of total social isolation suggests the long-term survival of these viruses in the station environment.

The outdoor environment at South Pole Station is cold and dry, with ambient temperatures ranging from −20°C in the midsummer (December) to below −70°C in the winter (July) and water vapor density (WVD) ranging as low as 0.004 grams per cubic meter. Such extreme conditions conceivably might enhance the long-term survival of human parainfluenza viruses in the outdoor environment and provide the source of infection for the midwinter RTI episodes observed in South Pole winter-over subjects. In addition, temperatures in buildings at South Pole Station are maintained at between 18° and 21°C, and the relative humidities in different buildings are low, varying from less than 8.0 percent to 33.3 percent (table 1). These dry indoor conditions also may favor the survival of human parainfluenza viruses.

Survival of parainfluenza virus types 1, 2, and 3 at South Pole Station was investigated during the 1981–82 summer season. Virus was deposited on the inner surfaces of sterile plastic petri dishes (19.6 square centimeters) as an aerosol generated by a Hudson nebulizer. The plates were stored inside (21.4°C; WVD, 1.5 grams per cubic meter) and outside the biomedical facility (−22.4° to −33.2°C; WVD 0.706 and 0.247 grams per cubic meter, respectively). They were then assayed for viable virus at 4-day intervals, using microplate cultures of continuous monkey kidney cells, until no further infectious virus could be recovered (table 2).

Table 1. Temperature, relative humidity, and water vapor density at South Pole Station

Location	Temperature (°C)	Relative humidity (%)	Water vapor density[a] (grams per cubic meter)
Biomedical building	21.4	8.0	1.50
Accommodation annex	18.2	16.5	2.82
Science building	19.8	33.0	5.87
Dome area[b]			
January	−26.9[c]	100	0.459
July	−61.0	100	0.0096
November	−48.0	100	0.048

[a] Water vapor density = saturated water vapor density at °C × relative humidity.

[b] Measurements were taken outside station buildings under the geodesic dome.

[c] Values are monthly average temperatures.

Parainfluenza virus type 1 at an initial titer of 3.78 $\log_{10}\mathrm{TCID}_{50}$ per milliliter (TCID_{50} being 50 percent tissue culture infectious dose) became inactive after 4 days at room temperature, and after 7 days in the outdoor environment. Parainfluenza virus types 2 and 3 (initial titers of 5.58 and 5.38 $\log_{10}\mathrm{TCID}_{50}$ per milliliter) became inactive after 7 and 12 days, respectively, at room temperature, and after 17 days of storage outside. These initial virus titers exceed the titer of virus usually recovered from human adult nasal secretions during infection by at least 1.0 to 2 $\log_{10}\mathrm{TCID}_{50}$ per milliliter.

These results clearly indicate that the long-term survival of parainfluenza viruses in either the indoor or outdoor environment at South Pole Station for up to 10 weeks is not likely; therefore, these environments would not provide the source of infectious virus responsible for the midwinter episodes of parainfluenza virus-related RTI's in this community. The survival of parainfluenza virus type 3 on a surface in this dry indoor environment for as long as 12 days was unexpected, because experiments by other workers have shown that this type of virus survives for only a few hours in a suspended aerosol at room temperature (Miller and Artenstein 1967). The transmission of human parainfluenza viruses has largely been attributed to direct aerosol droplet spread from person to person. While this

Table 2. Titers of human parainfluenza viruses recovered from surfaces stored under different environmental conditions at South Pole Station, by day of recovery

Time (days)	Parainfluenza 1		Parainfluenza 2		Parainfluenza 3	
	Inside	Outside	Inside	Outside	Inside	Outside
0	3.78[a]	3.78	5.58	5.58	5.38	5.38
1	2.30	2.80	3.54	3.30	4.59	4.49
4	0.00[b]	2.30	2.00	3.30	4.54	4.00
7	0.00	0.00	0.00	1.50	1.24	2.25
12	N.D.[c]	N.D.	N.D.	N.D.	0.00	1.34
17	N.D.	N.D.	0.00	0.00	0.00	0.00

[a] Values are means of triplicate determinations.

[b] Titer of 0.00 indicates that virus had become inactive.

[c] N.D. = not done.

is undoubtedly important in the perpetuation of infections within infant populations, because of the large amount of virus secreted during primary childhood illness, our results suggest that indirect nonaerosol transmission from surfaces also may be important in the survival of virus in adult populations where low titers of virus are shed during illness.

The storage of virus in the outdoor environment did not appear to enhance survival significantly despite temperatures of below −20°C. Although high-titered suspensions of parainfluenza viruses can be stored in an appropriate protein-containing medium at a constant temperature below −60°C for several years without loss in infectivity, storage temperatures of between −20° and −30°C have been shown to be the least suitable for influenza and parainfluenza virus survival (Hurrel 1967). The outdoor environment at South Pole during this study provided a constantly changing temperature gradient between −22.4° and −33.2°C, which may have contributed to the rapid virus inactivation under these conditions. We previously demonstrated the rapid inactivation of these viruses by temperature changes of between −70° and −200°C (Parkinson et al. 1980).

The exact mechanism of virus persistence and shedding we observed at South Pole Station during the winter-over period of 1978 is unknown. We do not believe these viruses survive for prolonged periods on surfaces in the South Pole environment. The long-term survival of human parainfluenza viruses in the upper respiratory mucosa of one or more subjects isolated at South Pole is a more likely explanation.

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Possible modification of summer season respiratory disease transmission in an open community at Scott Base

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Previous volunteer experiments in Madison, Wisconsin, showed that respiratory viruses were quite difficult to transmit, requiring an infected person to have a relatively severe cold and to spend many hours with a susceptible person (D'Alessio et al. 1976; Dick, Blumer, and Evans 1967; Dick and Chesney 1981). Our Madison experiments were confirmed at McMurdo Station and nearby Scott Base during three different winter fly-in periods in 1975–77. Cold virus dissemination was relatively slow, spreading mainly among persons who had close work or social relationships. Epidemic curves for respiratory illness were relatively flat, declining very little over time in either incidence or prevalence.

Following these Madison and antarctic experiments, we began exploring the possibility of interrupting transmission. A virucidal paper handkerchief (VPH) was developed which destroys viruses as they are shed from the nasal cavity and at points of likely mucous contamination such as the fingers, nose, and face (Dick et al. 1979). We used these tissues in an experimental effort to control respiratory disease outbreak at McMurdo Station during the 1979 winter fly-in periods, August 28 to October 7 (Dick et al. 1980). For the entire population of 233 persons, the number of new colds averaged 4.3 per day during the 18 days before VPH use and 1.7 per day during 18 days of VPH use ($x^2 = 33$, $p = < 0.01$). We then decided to repeat the experiment at Scott Base and its subsidiary field stations during the antarctic summer that immediately followed.

For our Scott Base VPH trial we elected to use longitudinally controlled study design consisting of (1) a period during which we monitored normal respiratory disease transmission with no VPH use (8–19 October), (2) a period during which VPH's were used to attempt transmission interruption, with expected decline in occurrence of new colds (20 October–8 November), and (3) a period during which VPH's were withdrawn from use, with expected increase in occurrence of new colds (9 November–28 November). During the period of VPH use, all persons with respiratory illness blew their noses into VPH's, which were then discarded. Each person then used a second VPH to wipe the nares, face, and fingers. Preventive use of VPH's also was instituted; each symptom-free individual used one tissue each hour to wipe nares, face, and fingers. We assumed that the first 4 days after VPH usage (20–23 October) represented both the approximate incubation period for colds already contracted as well as a period for persons to adjust to VPH usage. Any decline in respiratory illness after that period could be attributed to VPH usage.

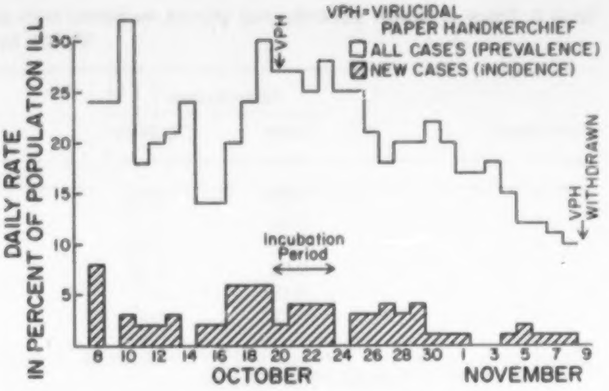

Figure 1. Respiratory disease occurrence at Scott Base and subsidiary field stations, antarctic summer 1979.

Our results are shown in figures 1 and 2. For Scott Base and all the field stations, an average of 3.2 percent of the population developed new colds before VPH use, and 1.6 percent developed colds during the period of VPH use ($x^2 = 5.2$, $p = < 0.05$). For the Scott Base population only, an average of 3.7 percent of the population developed new colds during the pre-VPH period, and 1.6 percent developed new colds during the period of VPH use ($x^2 = 4.9$, $p = < 0.05$). During the post-VPH period, there was a noticeable increase in illness prevalence, but incidence increased only slightly, to 1.8 percent per day (x^2 not significant).

Viruses were isolated throughout the study period and from

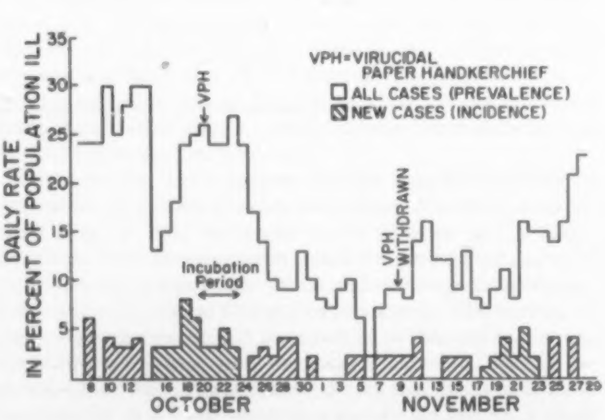

Figure 2. Respiratory disease occurrence at Scott Base only, antarctic summer 1979.

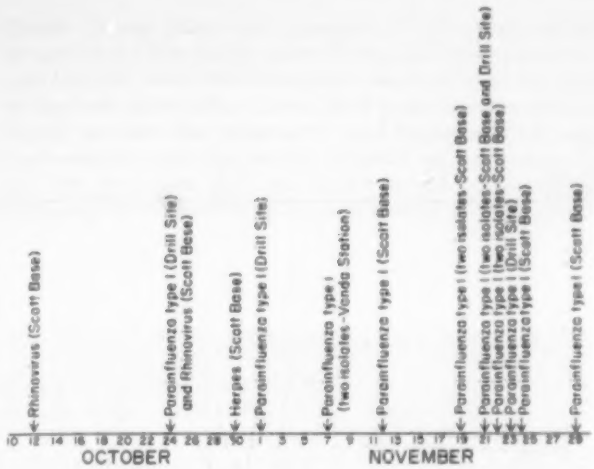

Figure 3. Virus isolation by date of specimen collection, Scott Base and subsidiary field stations, antarctic summer 1979.

all geographic sites (see figure 3). Of particular interest were 10 isolates of, and 12 additional serum antibody conversions to, parainfluenza type 1, indicating a significant epidemic at Scott Base. Parainfluenza type 1 epidemics typically occur in autumn and winter in the Northern Hemisphere, and the same seasonality would be expected in the Southern Hemisphere. This was, in fact, shown in New Zealand during a 3-year study of acute respiratory disease where parainfluenza type 1 was documented in June and July (Jennings, MacDiarmid, and Miles 1978). The occurrence of an epidemic caused by this same infectious agent in New Zealanders during the antarctic summer is unexpected. The most likely explanations for this outbreak would be the transmission of parainfluenza type 1 from (1) neighboring American antarctic personnel, or (2) New Zealand antarctic personnel infected in New Zealand. The latter hypothesis is of particular interest because parainfluenza would not be expected to circulate in the New Zealand population at this time of year, unless the islands had been rather substantially infected by travelers from the Northern Hemisphere.

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Lower atmosphere studies

Air chemistry monitoring at Palmer Station

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The objectives of this research program are to measure, continuously, the trace chemical constituents of the atmosphere at Palmer Station and to relate findings to meteorological conditions. The meteorological correlations will be sought on the basis of regional synoptic weather patterns and more general seasonal meteorological conditions. Air sampling will be conducted at the Anvers Island Air Chemistry Facility, so named at the station dedication on 16 January 1982 by Francis S. L. Williamson. The facility is equipped to measure, on a regular or continuous basis, the trace atmospheric parameters listed in the table. The frequency of measurement and the methods used are also shown in the table.

The air sampling facility is a separate building with a nominal floor space of 3 by 4.25 meters (10 by 14 feet) plus a 1.2 by 1.2 meter (4 by 4 foot) double-door entry vestibule for wind and weather protection. The station was prefabricated and then erected in a preliminary fashion at Washington State University, at which time the sampling instruments were set up and checked. Subsequently, the disassembled components were shipped to Palmer Station aboard the resupply ship USCGC *Polar Sea*. The facility is east of the main Palmer Station building complex and about 45 meters (150 feet) east of the old helicopter pad. Power for instrument operation and heat comes from the Palmer generating plant through a land line. A stainless steel air inlet stack 5 centimeters (2 inches) in diameter extending about 3 meters (10 feet) high above the building and leading to a connecting manifold inside is flushed by a small blower to provide a clean air source for the sampling instruments. Figure 1 is a photograph of the facility looking from west to east, with the Anvers Island glacier in the background. The air sampling inlet stack at the rear of the building is clearly visible. Figure 2 is a view from the glacier looking west toward Palmer Station. The facility is visible to the left of the Jamesway hut.

Some of the facility's simpler instruments—those for measuring ozone and Aitken nuclei—were placed in operation on 21 January 1982. Full operation of the system, including the computer-controlled data system, was achieved on 15 February 1982.

All instrument outputs are recorded by a Hewlett-Packard (HP) 85 data system which also provides the cyclic control signals for the gas chromatographs. Strip charts provide backup for the HP 85 computer system. The instruments are standardized against gas mixtures that were calibrated against known standards prior to shipment to Palmer. Long-term standards are maintained at Washington State University (WSU). The carbon dioxide (CO_2) data will be correlated with the National Oceanic and Atmospheric Administration's Geophysical Monitoring for

Trace atmospheric parameters measured and methods of measurement used at Anvers Island Air Chemistry Facility

Parameter	Frequency of measurement	Method of measurement
Ozone (O_3)	continuous	ultraviolet photometry (Dasibi)
Methane (CH_4)	1 per hour	automatic gas chromatography (Carle model 211)
Carbon dioxide (CO_2)	1 per hour	
Carbon monoxide (CO)	1 per hour	
CCl_3F (Freon 11, or F-11)	1 per hour	automatic dual channel gas chromatograph (Hewlett-Packard model 5880)
CCl_2F_2 (Freon 12, or F-12)	1 per hour	
Carbon tetrachloride (CCl_4)	1 per hour	
Methyl chloroform (CH_3CCl_3)	1 per hour	
Nitrous oxide (N_2O)	1 per hour	
Aitken nuclei (also known as condensation nuclei, or CN)	continuous	expansion-type photometric system (Environment One)

Climate Change (NOAA/GMCC) program. Weather data will be included in the data filed by manually transcribing the observations from the Palmer Station records. Recorded wind data and the response of the Aitken nuclei, or CN, counter will be used to identify periods when emanations from Palmer activities may be affecting the sampling results. Available wind records indicate that flow from the west, which would result in contamination by effluents from the main station, is not predominant. Sampling results and other data will be relayed to Pullman for further analysis as conditions permit.

The Anvers Island Air Chemistry Facility is expected to operate for 4 to 5 years. The measurements made at the facility can be expanded as new instruments adaptable to the rugged Palmer environment and to low background levels become available. The sampling results are expected to complement NOAA/GMCC air-sampling data collected at Amundsen-Scott South Pole Station and the data gathered at the Australian background station at Cape Grim, Tasmania. Although the WSU program focuses on the interaction of air chemistry patterns and synoptic weather situations, the facility also can provide support for other investigators interested in air chemistry and related studies.

Support services by ITT-Antarctic Services, Inc., assisted greatly in the safe shipment and arrival at Palmer of the large amount of material required to establish this program. In addition to the authors, Fred Menzia, WSU research technician, assisted in the establishment of the station; Menzia continued on as the 1981–82 winterover scientist for the program.

This research was supported by National Science Foundation grant DPP 80-05797.

Figure 1. The Anvers Island Air Chemistry Facility established at Palmer Station, January 1982, by Washington State University.

Figure 2. View of Palmer Station looking west from Anvers Island glacier. Air chemistry facility is visible to the left of the Jamesway hut.

Climate of Dome C

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During the austral summer of 1979–80, the United States and France began an experiment on the katabatic wind along the Adélie Coast and in Wilkes Land (Wendler and Poggi 1980). The United States used automatic weather stations built by Stanford University and now maintained and operated by the University of Wisconsin to make measurements between Dome C (74.5°S 123°W; 3,280 meters) and D-10 (66°40'S 140°01'E, near Dumont d'Urville Station; 267 meters); the French took measurements at five sites in the immediate coastal area of Dumont d'Urville. The U.S. measurements are transmitted via satellite, while the French data are telemetered to Dumont d'Urville. In addition to these ground-based measurements, measurements with the instrumented LC-130 also were carried out. In this article we are not so much reporting on overall progress as commenting on

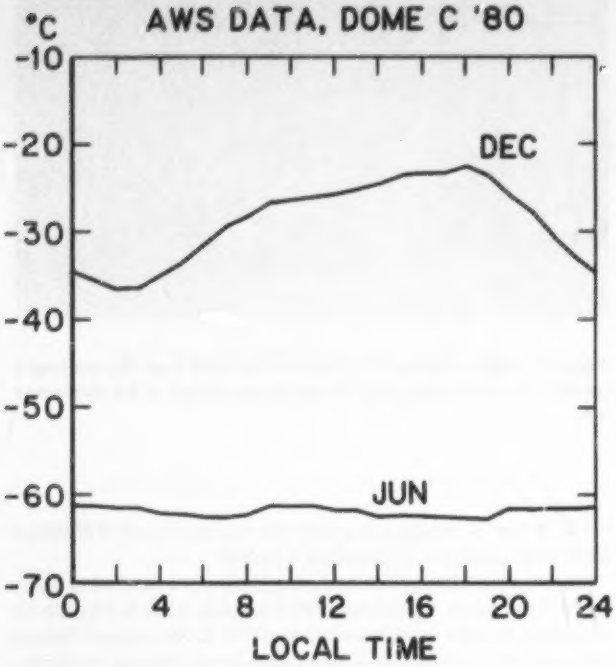

Figure 1. Mean diurnal temperature course during a summer (December) and winter month (June) at Dome C (3,280 meters).

the climate of Dome C, because we now have a 2-year database showing some unique characteristics for Antarctica.

Dome C was chosen for katabatic wind experiments because it is the highest point in the area (3,280 meters above sea level, which is a corrected value from previous reports). It is about 1,090 kilometers from Dumont d'Urville. The surrounding area is very flat, with slopes of less than 1:10,000. Since Dome C is the highest point in its surroundings, there should be no katabatic wind in this area. Most of the surface climatology of antarctica is influenced by this phenomenon; in fact, we are not aware of any single meteorological parameter on any continent that influences the climate of an entire continent as much as the katabatic wind does in Antarctica.

Figure 1 shows average temperatures for the months of June and December 1980. For the winter (June), the temperature remained somewhat below −60°C throughout the day; the absence of systematic diurnal variation is not unexpected, since the Sun is below the horizon throughout the month. In summer (December), there is a pronounced diurnal range of 14°C, with a maximum of −22°C and a minimum of −36°C and a mean monthly temperature of about −29°C. Although the Sun is above the horizon throughout the day, Dome C is far enough away from the South Pole that there are substantial differences in the height of the Sun during the 24-hour cycle.

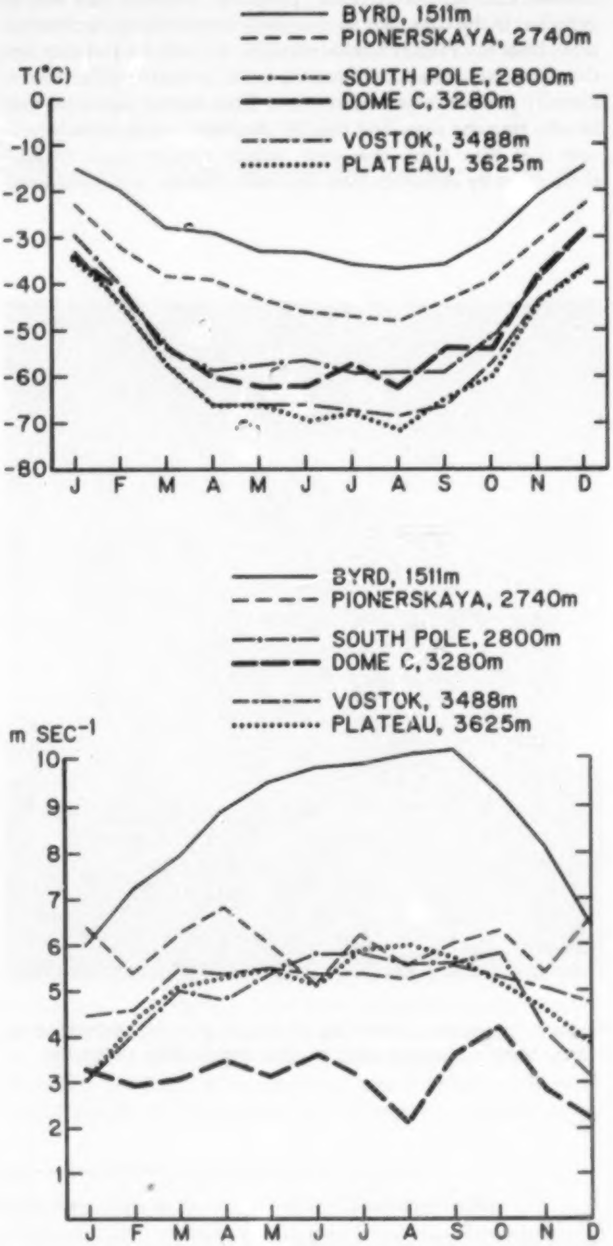

Figure 2. Annual course of temperature (top) and wind speed (bottom) at Dome C in comparison with other inland stations in Antarctica.

Figure 2 (top) compares the annual temperature cycle at Dome C with the cycles at other inland stations in Antarctica. For its altitude, Dome C fits very well in to the general picture that could be derived from the other, longer term climatological stations. It is cooler than the lower Byrd (1,511 meters) and Pionerskaya (2,740 meters) stations, but warmer than the higher Vostok (3,488 meters) and Plateau (3,625 meters) stations. Its annual temperature is most like that at South Pole Station, which is somewhat lower in altitude (2,800 meters). The somewhat more irregular annual temperature course at Dome C reflects the short observation period there (2 years) compared with that at the other stations. The absolute minimum measured at Dome C was −79.7°C; looking at the annual course, one would not expect a new absolute world minimum to be recorded at this station.

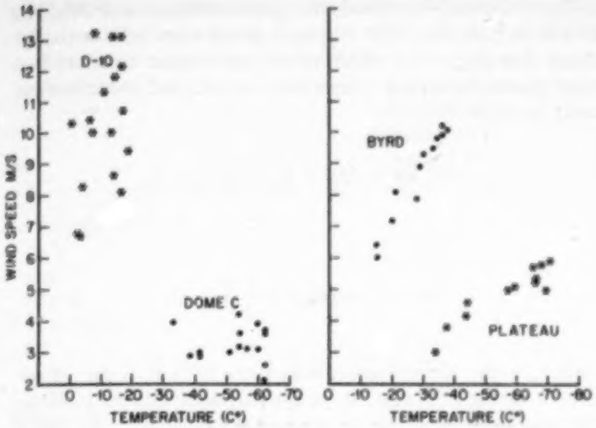

Figure 3. Monthly mean values of wind speed plotted against temperature at automatic weather stations (AWS) at D-10 and Dome C, and at two longer term inland stations in Antarctica.

As expected and reported previously (Wendler, Gosink, and Poggi 1981), the wind at Dome C is light. In fact, wind speed there is by far the lowest of all inland stations in Antarctica (figure 2, bottom). The mean annual value is around 3 meters per second, and there appears to be no annual cycle. The wind speed at Dome C is not only the lowest of all inland stations, but also the lowest among all antarctic stations, including coastal and near-coastal stations. This is unique because a freely exposed station at a height of 3,280 meters on all other continents would have a higher wind speed than many coastal stations. This shows again the influence of the katabatic wind.

The driving force of the katabatic wind is, of course, the difference in temperature between the air near the ground and the air at the same altitude further down the slope. This temperature difference is a function of inversion strength, which is best developed during the winter months when there is no heating of the surface by solar radiation. This is also the coldest time of year. Hence, if a place is dominated by gravity flow, one would expect a relationship between temperature and wind speed such that the colder the temperature, the stronger the wind. Looking at two inland stations (Plateau and Byrd) (figure 3), we can see that this relationship is very well established for the monthly mean values. This relationship also holds at D-10, although there is somewhat more scatter because these data are single monthly values, not long-term monthly means as reported for Byrd and Plateau. Dome C shows no relationship whatsoever between temperature and wind. This result, showing the absence of any gravity flow, is to be expected. The increase in wind speed with decreasing temperature makes the climate of Antarctica inhospitable. The opposite is true for the interior of Alaska; as the inversion builds up over flat areas, there is no gravity flow and the inversion suppresses transmission of the wind speed aloft to the surface. Hence, during cold spells the winds are absent or very weak, while stronger winds destroy the inversion at least partly and bring warmer air to the surface. Antarctica, in contrast, shows the worst possible combination for human occupation: the colder the surface temperature, the stronger the winds become, resulting in extremely low "equivalent chill temperatures."

This work is being supported by National Science Foundation grant DPP 81-00161. Allen Peterson's group of Stanford University designed the stations, and Charles Stearns and coworkers of the University of Wisconsin have refined the units, improved their performance, and provided for maintenance, operation, and preliminary data analysis. To these people, as well as to Expeditions Polaires Françaises, and especially to its director, Jean Vaugelade, we are extremely thankful. A. Schmidt and J. Gosink went to Antarctica, and F. Eaton reviewed this article. Our thanks are extended to all these people.

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Atmospheric fluorocarbons and methyl chloroform at the South Pole

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The ultimate aim of our research is to determine exactly how human activities are modifying the composition of the Earth's atmosphere and what effect these changes will eventually have on the global environment. It is feared that long-lived gases such as carbon dioxide (CO_2) released into the atmosphere by industrial processes and other human activities eventually may increase the Earth's surface temperature by enhancing the natural greenhouse effect. Gases containing chlorine (and bromine)—much as CCl_3F (fluorocarbon-11; F-11) and CCl_2F_2 (fluorocarbon-12; F-12)—may deplete the stratospheric ozone layer, thus allowing more ultraviolet radiation to reach the Earth's surface and harming living organisms (Barney 1980; National Academy of Sciences 1979).

In this article we discuss changes in the atmospheric abundances of the manmade gases CCl_3F, CCl_2F_2, $CHClF_2$ (fluorocarbon-22; F-22), $C_2Cl_3F_3$ (fluorocarbon-113; F-113), and CH_3CCl_3 (methyl chloroform) over the past 8 years. These gases may not only deplete the ozone layer but may also add to global warming. The very presence of these gases at the South Pole, at concentrations not much less than those in the Northern

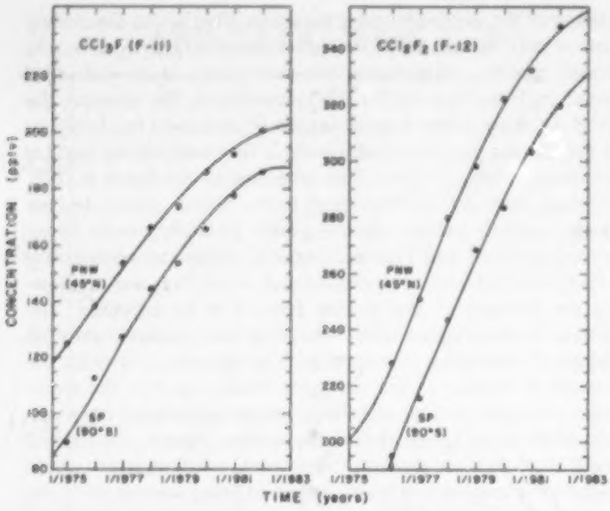

Figure 1. Observed concentrations of fluorocarbon-11 (CCl_3F) and fluorocarbon-12 (CCl_2F_2) at the South Pole (lower lines) and in the Pacific Northwest (PNW; 45°N; upper lines). The solid line is the function $C = C_o \exp(\beta_o t + \frac{1}{2} \delta t^2)$.

Hemisphere, attests to their long atmospheric lifetimes and their great potential for accumulating in the environment. We are reporting, for the first time, steady increases of F-22 and F-113 at the South Pole; our latest observations on F-11, F-12, and CH_3CCl_3 show that these gases are not increasing as rapidly as they did in earlier years.

We started observing concentrations of F-11 and CH_3CCl_3 at the South Pole in January 1975, and the first measurements of F-12 were made in January 1976. We have continued these measurements every January since then. The 8 years of data comprise the longest systematic and internally consistent measurements currently available. It is being recognized that F-22 and F-113 may also be important environmental contaminants. Techniques for the atmospheric measurement of these extremely rare fluorocarbons have been developed only recently. The measurements of these gases at the South Pole since January 1979 are the first and only ones available. To provide a contrast for the antarctic measurements, the concentrations of these gases were also measured in the Pacific Northwest (in Oregon and Washington at about 45°N) during January of every year. Concentrations of these five gases are measured by electron capture gas chromatography techniques. Discussions of the early data on F-11, F-12, and CH_3CCl_3 and of the analytical techniques can be found elsewhere (Khalil and Rasmussen 1981; Rasmussen 1978; Rasmussen and Khalil 1980; Rasmussen, Khalil, and Dalluge 1980; Rasmussen, Khalil, Penkett, and Prosser 1980).

The results are shown in figures 1 and 2. The rate of change was determined by the formula $(1/C)\ dC/dt = \beta(t)$, where C is concentration and t is time. This relative expression is used because it does not depend on knowing the absolute concentration of a trace gas (accuracy); only relative changes (precision) need be known. The precision of measurements for these gases is very high at ≤ 2 percent. It is believed that the annual global emissions of F-11 and F-12 have not changed much since 1975, whereas before 1975 they had been increasing very rapidly. The yearly increase in the global emissions of CH_3CCl_3 has also slowed since 1975. A simple global mass balance model reveals that $\beta(t) = 1/C\ dC/dt$ would not remain constant but would gradually decline. Therefore, we adopted the following model for $\beta(t)$:

$$(1/C)\frac{dC}{dt} = \beta(t) \simeq \bar{\beta}_o + \bar{\delta}_t, \ \bar{\delta} < 0,$$

or

$$C \simeq C_o \exp(\bar{\beta}_o t + \frac{1}{2}\bar{\delta} t^2),$$

where C_o is the concentration in January 1975, $\bar{\beta}_o$ is the rate of increase during 1975, and $\bar{\delta}$ is the gradual decline in the increase with time since 1975. The most suitable values of C_o, $\bar{\beta}_o$, and $\bar{\delta}$ were determined by a nonlinear least squares criterion and are reported in the table. The results for F-11, F-12, and CH_3CCl_3 derived from the second equation are shown as solid lines in figures 1 and 2. The results imply that F-11, F-12, and CH_3CCl_3 are not increasing as rapidly as they did during the 1970's; this observation is consistent with current knowledge of global anthropogenic sources.

Much less is known about the global sources and sinks of F-22 and F-113. It is certain, however, that their atmospheric concentrations are rising rapidly, as shown in figure 2 and in the table, and this is cause for concern about the future global environment (see also Khalil and Rasmussen 1981; Rasmussen, Khalil, Penkett, and Prosser 1980).

In addition to the fluorocarbons and CH_3CCl_3, concentrations of 15 other trace gases have been measured at the South Pole and in the pacific Northwest since 1979 or earlier, namely, CCl_4 (carbon tetrachloride), N_2O (nitrous oxide), CH_3Cl (chloromethane), SF_6 (sulfur hexafluoride), CO (carbon monoxide), CH_4 (methane), C_2H_2 (acetylene), C_2H_4 (ethylene), C_2H_6 (ethane), C_6H_6 (benzene), C_7H_8 (toluene), C_3H_8 (propane), CH_3I (methyliodide), $CHCl_3$ (chloroform), and C_2HCl_3 (tri-

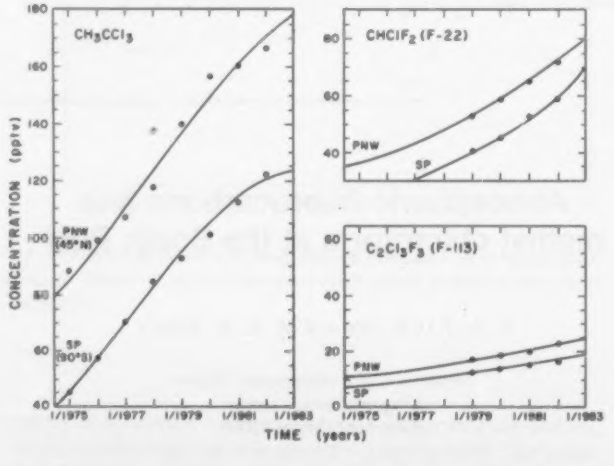

Figure 2. Observed concentrations of fluorocarbon-22 ($CHClF_2$), fluorocarbon-113 ($C_2Cl_3F_3$), and methyl chloroform (CH_3CCl_3) at the South Pole (SP; lower lines) and in the Pacific Northwest (PNW; upper lines). The solid line is the function $C = C_o \exp(\bar{\beta}_o t + \frac{1}{2}\bar{\delta} t^2)$ for CH_3CCl_3 and $C = C_o \exp \bar{\beta}_o t$ for F-22 and F-113.

Yearly increase in halocarbon concentration and slowdown of atmospheric accumulation at the South Pole (SP; 90°S) and in the Pacific Northwest (PNW; 45°N)

Gas	Average concentration in base month[a] (pptv)	β_o (% per year)	δ (% per year, per year)	Coefficient of determination (r)	n[b]
F-11 (CCl_3F)					
SP	92	18	−2.4	0.997	8
PNW	125	11	−1.2	0.999	8
Global	109	14	−1.8	0.999	8
F-12 (CCl_2F_2)					
SP	170	13	−1.4	0.999	7
PNW	201	12	−1.6	0.999	7
Global	186	12	−1.4	0.999	7
Methyl chloroform (CH_3CCl_3)					
SP	46	24	−2.8	0.997	8
PNW	84	15	−1.4	0.991	8
Global	65	18	−1.8	0.999	8
F-22 ($CHClF_2$)					
SP	40	13		0.999	4
PNW	53	10		0.996	4
Global	46	11		0.996	4
F-113 ($C_2Cl_3F_3$)					
SP	12	9		0.974	4
PNW	16	10		0.986	4
Global	14	10		0.991	4

Note. The rate of change of trace gas concentration is assumed to follow the equation $\left(\frac{1}{C}\right)\frac{dC}{dt} = \bar{\beta}_o - \bar{\delta}t$. $\beta_o = 100\,\bar{\beta}_o$ (percent per year) and $\delta = 100\,\bar{\delta}$. Concentrations of F-11, F-12, and CH_3CCl_3 started rising at β_o percent per year around 1975, but this rate declined on the average by δ percent per year per year since then.

[a] For F-11, F-12, and methyl chloroform, base month was January 1975; for F-22 and F-113, base month was January 1979. In parts per thousand, by volume.

[b] Number of years measurements were made.

chloromethane). Results of these measurements are reported elsewhere (Rasmussen and Khalil in preparation; Rasmussen et al. 1981.)

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Hydroxyl radical measurements

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This research was directed toward determining the hydroxyl radical concentration in the mid-January, lower tropospheric antarctic air. Current thought is that the hydroxyl radical plays a central role in the Earth's atmospheric photochemistry as an oxidant of trace gases, including carbon monoxide (CO), methane (CH_4), and methyl chloroform (CH_3CCl_3). Campbell (1980) has shown that the lifetimes of these trace gases are shortest in the equatorial latitudes and longest near the poles because of their inverse dependence on the tropospheric hydroxyl radical concentration. Thus, most of the photochemical oxidation in the Earth's atmosphere occurs between the Tropics of Cancer and Capricorn (22°N to 22°S). Measurement of hydroxyl radical concentrations at various latitudes would test this hypothesis.

During the 1981–82 austral summer, Washington State University (WSU) researchers (authors Hopper and Hardy) took hydroxyl radical measurements at McMurdo Station and at the South Pole. The carbon-14 tracer method (Campbell, Sheppard, and Au 1979) used in these measurements involves the injection of very pure carbon-14 labeled carbon monoxide (^{14}CO) into a 100-liter ultraviolet-transparent Teflon reaction vessel, and then the rapid removal of small aliquots (3 to 14 liters) at reaction times ranging between 20 and 90 seconds. During this reaction time, a small fraction of the ^{14}CO is photochemically oxidized to $^{14}CO_2$ by the hydroxyl radical. Samples containing $^{14}CO_2$ were returned to the WSU radiocarbon dating laboratory for additional purification and were counted in low-level methane proportional counting tubes to determine their $^{14}CO_2$ contents. Plots of the fraction of ^{14}CO converted to $^{14}CO_2$ as a function of time yield slopes that are proportional to the hydroxyl radical concentrations. Because of low-level ^{14}C contamination in some of the collection tubes, it was necessary to treat the data from the four McMurdo experiments, conducted under nearly identical reaction conditions, in a single time-averaged regression analysis. The important reaction conditions—ozone (O_3) water vapor (H_2O), temperature, and ultraviolet intensity—were determined in parallel with each hydroxyl radical measurement. The supplementary data [O_3, H_2O, temperature, and J(O^1D), the photoproduction rate of metastable oxygen] and the results of four McMurdo and three South Pole hydroxyl radical measurements are summarized in tables 1 and 2, respectively.

Measurements were conducted upwind of local sources of hydrocarbons, carbon monoxide, and nitrogen oxides (e.g., aircraft and vehicular traffic) that could alter ongoing atmospheric photochemistry and hydroxyl radical concentrations. McMurdo experiments were carried out at a site just upwind (east) of the radio transmitter station between 10 and 12 January 1982. Atmospheric conditions varied from clear to high, thin, cirrus clouds with winds gusting between 10 and 15 knots. South Pole experiments were conducted at a site due west of the Clean Air Facility along the boundary of the clean air quadrant on 20 January 1982. The sky was clear and the wind speed was about 4 knots.

Analysis of the data obtained from these hydroxyl radical experiments indicated that (1) the background $^{14}CO_2$ signal of the apparatus was equivalent to 250,000 hydroxyl radicals per cubic centimeter; (2) the average concentration of midday, mid-January tropospheric air at McMurdo was less than 400,000 hydroxyl radicals per cubic centimeter, the upper limit value a result of ^{14}C contamination in the collection system; and (3) at the South Pole, the measured hydroxyl radical concentration was between 90,000 and 540,000, with an average of 320,000 for three determinations. Low-level ^{14}C contamination was also responsible for the spread in the South Pole data.

Using a simple steady state model, the data in table 1, Rasmussen, Khalil, and Dalluge's (1980) antarctic CO, and the probable range of nitrogen oxide (NO_x) concentrations, hydroxyl radical concentrations were calculated for each of the reported measurement sites. Table 2 contains these estimated and measured hydroxyl radical concentrations; for comparison, values measured at Pullman, Washington, and at Barbados Islands in the Caribbean are included.

The calculated and measured hydroxyl radical concentrations at the antarctic sites are in reasonable agreement in view of the large uncertainties in both the model calculations and in the

Table 1. Supplemental data for antarctic hydroxyl radical experiments

Measurement	Temperature (°C)	Water vapor (mm mercury)	Ozone (parts per billion)	J(O^1D)[a] (10^{-6} per second)
McMurdo				
MCM-1	−0.6	2.9	—	1.0
MCM-2	−4.0	2.2	—	0.98
MCM-3	−3.0	2.4	—	0.78
MCM-4	−3.0	2.4	—	0.98
Average, MCM	−2.6 ± 2.3	2.5 ± 0.5	8.9 ± 0.3[b]	0.92 ± 0.18
South Pole (POL-2, 3, 4)	−30.4[c]	0.32[c]	7.1[c]	0.51 ± 0.1

[a] Photoproduction rate of metastable oxygen.

[b] Average of 31 concurrent ozone measurements.

[c] Data supplied by Lt. R. G. Williscroft, Station Chief, National Oceanic and Atmospheric Administration, Geophysical Monitoring for Climate Change, South Pole.

Table 2. Measured and calculated Hydroxyl radical (OH) concentrations

Measurement site	Latitude	Measured OH (per cubic centimeter)[a]	Calculated OH (per cubic centimeter)[b]	Amount of nitrogen oxide assumed in calculation (ppt)[c]
McMurdo Station (combined regression)	77.9°S	$<4 \times 10^5$	1.5×10^5	0
			3.8×10^5	30
South Pole	90°S	0.9×10^5 to 5.4×10^5	0.12×10^5	0
			0.44×10^5	30
Pullman, Wash. (average of 6 runs)[d]	46.7°N	$5.4 \pm 1.6 \times 10^6$	2.8×10^6	0
			4.4×10^6	100
Ragged Point, Barbados (average of 6 runs)[d]	13.5°N	$12.5 \pm 7.6 \times 10^6$	5.2×10^6	0
			9.4×10^6	100

[a] All measurements made under midday, clear-sky, summertime conditions.

[b] Supplemental data in table 1 used in these calculations.

[c] ppt = parts per trillion.

[d] These data taken from Campbell and Sheppard (in press).

measurement of very low radical concentrations near the detection limit of a partially contaminated apparatus. Taken as a whole, these measurements suggest that the summertime, midday hydroxyl radical concentrations in antarctic tropospheric air certainly are below 500,000 per cubic centimeter, and probably are lower. We believe with uncontaminated equipment this measurement method easily could detect hydroxyl radical concentrations below 500,000 per cubic centimeter, and possibly as low as 30,000. The latter would require extreme precautions to avoid all forms of ^{14}C contamination.

Comparison of the McMurdo and South Pole data with previous measurements made at Pullman, Washington, and at Barbados indicates that the hydroxyl radical concentration is highest in the tropics, lowest in the antarctic polar region, and intermediate in the midlatitudes. Obviously, many more measurements must be made to determine clearly the distribution of hydroxyl radical concentrations in the Earth's atmosphere. Thus, additional measurements of hydroxyl radical concentrations in antarctic air are also desirable.

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Infrared atmospheric transmission and emission measurements, South Pole Station

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Atmospheric measurements were made from the clean air facility at South Pole Station during the period 21 November to 15 December 1981. Two measuring instruments were used. One was a high-resolution Fourier transform spectrometer (FTS), used to record atmospheric absorptions in the solar spectrum in the 3–5 micrometer and 10–12 micrometer wavelength regions. The second was a grating spectrometer designed to measure emission from the atmosphere; for this initial run, it was set to scan a wavelength range of 17–28 micrometers.

The FTS measurements in the 10–12 micrometer wavelength region were selected to provide data on the same wavelength region as measured in previous years, providing a database to investigate the possibility of long-term fluorocarbons 11 and 12 (F-11, F-12), ozone (O_3), and nitric acid (HNO_3) above the Pole. The measurements in the 3–5 micrometer wavelength region were being taken for the first time; they will extend the data set beyond the wavelength range covered in the recently published *Atlas of South Pole IR Solar Spectra* (Blatherwick et al. 1982). Conditions at South Pole Station are highly favorable for observing trace gases in the atmosphere whose spectral signatures may be masked by other absorptions at lower, more humid sites.

The spectral radiometer measurements had several objectives: (1) determination of the total H_2O (water vapor) content of the atmosphere above South Pole Station, (2) comparison of the H_2O quantities determined from emission and absorption measurements, and (3) investigation of several parameters that will be useful in the design and construction of two instruments intended to make winter observations of the concentrations of H_2O, O_3, F-11, F-12, HNO_3, and, possibly, N_2O_5 (nitrogen pentoxide) over the South Pole (one of the most important of these parameters is the radiative properties of the ice crystals usually present at variable concentrations in lower atmospheric layers).

The FTS system was operated through an open window of the clean air facility. As in previous years, this was quite satisfactory for measurements at the longer wavelengths (i.e., 7–12 micrometers); however, degradation was noticed in the quality of the 3–5 micrometer data due to building vibrations and thermal turbulence in the interior-exterior air interface. To minimize these effects, the instrument was operated from the entrance deck. Several exceptionally clear days occurred during the period of observation, and FTS data were taken on 6 days (3 days for each region).

The spectral-radiometer system is designed to be most accurate when the entrance area of the spectrometer is at ambient temperature; therefore, it was set up on a plywood platform approximately 10 meters from the clean air facility. Data were taken at several elevation angles and under both clear and overcast conditions. After approximately 10 days of operation, the detector-dewar developed a thermal leak, which increased the boiloff rate of the liquid helium coolant. However, hold times were sufficient to permit short periods of data collection each day until the liquid helium supply dewars were exhausted.

The data currently are being studied to determine operating parameters for the winter-over instruments under construction. Analysis of the data from previous seasons is continuing, and portions of the high-resolution solar spectra have been published as a spectral atlas (Blatherwick et al. 1982). A paper discussing nitric acid column densities over Antarctica will be published soon (Williams, Kosters, and Murcray in press).

The main objective of this research is to obtain data on the atmospheric concentration and distribution of constituents over the South Pole. The spectra recorded by our various infrared instruments contains information not only about the total column amounts of various species, but also about the altitude distribution of the constituents. The amount of altitude information that can be obtained from such spectra is the subject of another paper that will be published soon (Goldman et al. in press).

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Investigation of aerosol transport processes at McMurdo and South Pole

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The Atmospheric Sciences Research Center has been engaged in the study of meteorological transport of particulate material to Antarctica for several years. This work continued through austral summer 1981–82, at McMurdo Station with cooperation from M. Pomerantz's group (Bartol Research Foundation, University of Delaware) at the cosmic ray observatory and from LCDR Foster's aerologists (U.S. Naval Support Force Antarctica), and at South Pole Station in cooperation with the National Oceanic and Atmospheric Administration's Geophysical Monitoring for Climatic Change (NOAA/GMCC) program. In addition, a new series of meteorological observations was begun at South Pole in cooperation with the Antarctic Services, Inc., station meteorological team.

The aerosol and atmospheric ion measurements obtained during the 1981 austral winter indicate that air arriving at McMurdo Station from the interior of the continent is not appreciably altered in aerosol concentration as it passes over the Ross Ice Shelf. Results of similar measurements made during the same time period at high northern latitudes have been obtained from B. Bodhaine (NOAA/GMCC), and a comparative analysis is in progress. The aerosol, atmospheric ion, and ozone instrument at McMurdo was inspected and repaired during November, and observations continue.

Supporting aerosol and atmospheric ion measurements made at South Pole indicate that there is a measurable flux of atmospheric ions to the ice surface, which is related to vertical wind velocity. This flux is comparable to aerosol scavenging of atmospheric ions, but it has not, to this time, been included in most ion balance calculations. The clean air facility at South Pole proved to be an ideal site for this experiment because it presents uncontaminated air over a uniform surface.

At South Pole, aerosol measurements at the clean air facility were compared with meteorological data and with observations of suspended and precipitating ice crystals. Previous work has shown that an aerosol-enriched layer generally is present a few hundred meters above the south polar plateau, but that it is isolated from the surface by the strong temperature inversion. Increased concentration of aerosol is observed at the South Pole when mechanical mixing (due to wind shear) or ice crystal precipitation causes air from this layer to be transported to the surface.

A series of slow-rise meteorological balloon soundings was carried out during the latter half of the austral summer to study the temperature, humidity, and wind structure of air below the 500-millibar level (i.e., approximately the lower 3 kilometers), with the ultimate purpose of investigating the nature of this inversion and the mechanisms that cause transport across it. Moist advection phenomena, analogous to midlatitude warm fronts, preceded enhanced ice crystal precipitation.

A climatology of winds and temperatures, by month and season for the layers between the south polar surface and 50 millibars, has been compiled from the existing radiosonde archive. This climatology shows the most frequent stratospheric winds from the south to east (grid) quadrant and the most frequent tropospheric winds from the north to west (grid) quadrant. This climatological summary is available on request from the Atmospheric Sciences Research Center.

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Atmospheric infrasonic waves

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Atmospheric infrasonic waves with periods of 1–100 seconds were measured at Windless Bight southeast of McMurdo Station throughout the 1981 season. In January 1982, an upgraded digital data acquisition and real-time analysis system was installed at McMurdo Station, in a new building next to the cosmic ray building, to record the infrasonic wave data being telemetered from Windless Bight.

A data-adaptive pure-state filter (see Sampson and Olson 1981) was incorporated in the new digital analysis system at McMurdo that allows us to detect coherent signals that are 16 decibels below the ambient wind noise level. This online frequency domain filtering technique has resulted in the detection of ten times more coherent waves than were previously observed.

A second PDP 11/03 microcomputer and digital tape drive was added to the infrasonic equipment to enable the winterover operator to conduct offline analysis of various infrasonic wave events. For example, the eruptions of Chichonal volcano in Mexico on 29 March and 4 April 1982 produced waves that were detected by the real-time digital analysis system at Windless Bight from both the direct and the antipodal great circle paths. The digital tapes from these volcanic signals were then analyzed using the offline computer to provide spectral and wave number-frequency information for estimating the energy released by the eruption.

Digital tapes from the 1981 season were reanalyzed using the pure-state filter in order to enhance the signals. As a result of this enhancement, infrasonic waves from mountainous regions were observed in the antarctic data for the first time. Mountain-associated infrasound (MAI) has been observed in North America by Bedard (1978) and by Larson and others (1971). The antarctic MAI occurrence is shown in figure 1, in which the MAI wave packets observed in 1981 are plotted as a function of azimuth of

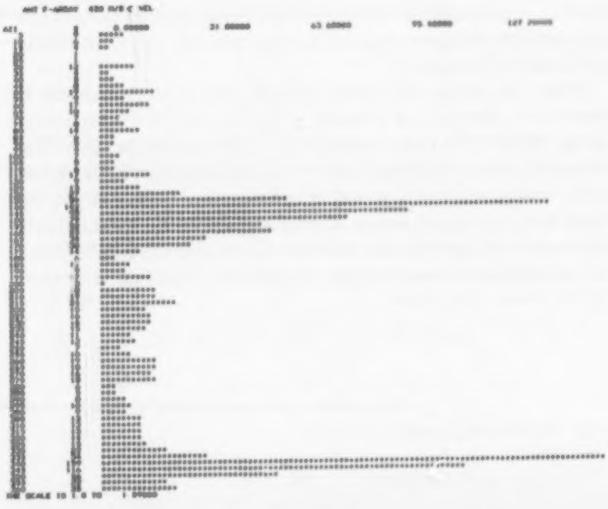

Figure 1. Number of mountain-associated waves as a function of azimuth of arrival, 1 January 1981–1 January 1982. Column 1—azimuth in five-degree increments; column 2—number of signals in each azimuth interval.

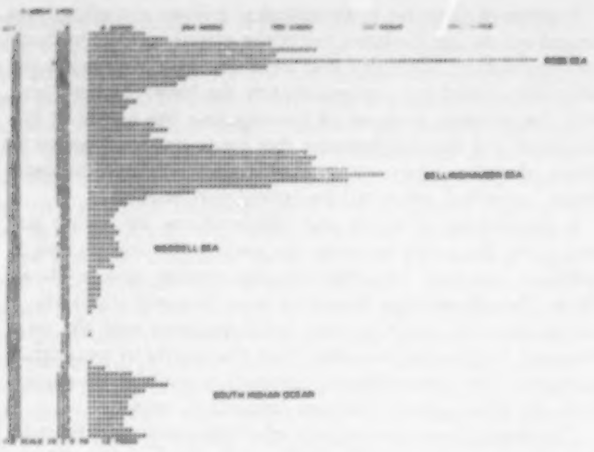

Figure 2. Number of microbaroms as a function of azimuth of arrival for 1981. Column 1—azimuth in five-degree intervals; column 2—number of microbarom signals in each azimuth interval.

arrival. The two principal directions from which MAI is observed are 135°–150°, the direction of the Antarctic Peninsula, and 335°–355°, the direction of the Victoria Land mountains. Additional observations and data analysis will be necessary to identify the exact geographic location of the MAI sources. The period of the observed MAI is about 50 seconds.

Five-second-period microbarom infrasonic waves generated by standing sea-surface waves during marine storms are observed at Windless Bight from four principal directions, as can be seen in figure 2. These four microbarom source regions can be identified with the quasistationary barometric lows in the Ross Sea, the Bellingshausen Sea, the South Indian Ocean, and the Weddell Sea. There is a very large seasonal variation in the source regions from which microbaroms are observed. At present it is not known whether this is a variation in source strength effect or a propagation effect. Further analysis and correlation with satellite images of ice cover are necessary to understand this seasonal variation.

When the horizontal trace velocity (V) of microbaroms is plotted as a function of azimuth of arrival (AZ) of the incoming waves (figure 3), a clear variation of V with AZ can be seen. The measured horizontal trace velocity of a microbarom wave packet is the sum of the scaler sound speed and the component of the wind speed in the direction of propagation at the stratospheric reflection height of the ray path (see Donn and Rind 1971). Thus the variation in V as a function of direction of arrival, averaged over an entire year of data (1981 in figure 3), is the result of the average stratospheric wind flow on the various microbarom propagation paths from the source region to Windless Bight.

An analysis of 14.5 million digital readings of infrasonic microphone pressure for 1981 has shown that the average value of the RMS (root-mean-square) noise level in the passband from 10- to 100-second periods is 1.07 microbars, confirming that Windless Bight is one of the most quiet sites on Earth.

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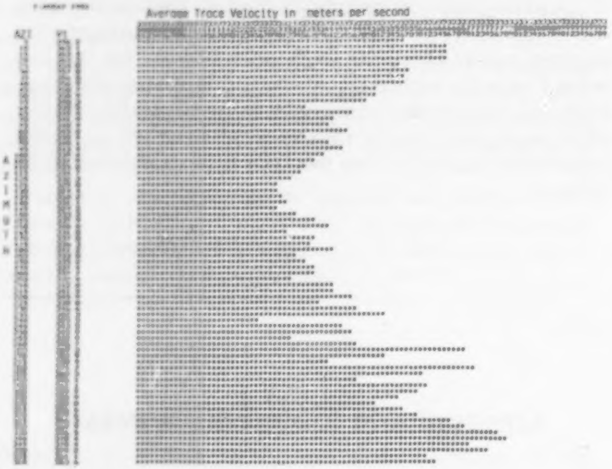

Figure 3. Horizontal trace velocity for microbaroms versus azimuth of arrival for 1981. Column 1—azimuth interval; column 2—average trace velocity.

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Contribution of Mount Erebus to the antarctic sulfate budget

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Sulfate constitutes a significant fraction of the antarctic aerosol. The source of this sulfate is uncertain (Boutron and Delmas 1980; Herron 1982; Maenhaut et al. 1979; Shaw 1979, 1980). Mount Erebus, on Ross Island, once was considered a possible source, but preliminary measurements led to the conclusion that its contribution is insignificant (Polian and Lambert 1979; Shaw 1979). Recent, more detailed measurements, which I carried out aboard the LC-130R aircraft operated by the Navy for the National Science Foundation, indicate that this conclusion should be reconsidered.

Mount Erebus, a 3,794-meter composite volcano, is the only antarctic volcano south of 63° latitude that is currently emitting significant amounts of trace gases and particles (Polian and Lambert 1979). Its crater is always filled with magma, and there are numerous active fumaroles and vents throughout the crater area. Mount Erebus is noted for its lava lake and for long periods of minor strombolian eruptive activity. Sir James C. Ross noted its extended plume in 1841, as did Robert F. Scott in 1902 (Quartermain 1967). However, the volcanic activity of Mount Erebus is quite variable (Kyle, Giggenbach, and Keys 1976). During observations in November 1980, the plume from Mount Erebus was visible on every fair day and sometimes could be seen extending up to 100 kilometers from the mountain.

To obtain quantitative estimates of the fluxes of particles and gases, measurements were taken as the LC-130R repeatedly traversed the plume of effluents, from top to bottom in vertical sections normal to the axis of the plume. The plume's cross-sectional dimensions were determined by means of continuous measurements of either Aitken nuclei or sulfur gases. These continuous measurements also were used to trigger bag sampling of the effluents near the plume's center. The sulfur gas analyzer could sample either from the bag or from the free air stream. The total output of the various substances per second (the flux) can be conceptually considered to be merely the cross-sectional area times the wind speed times the concentration. The wind speed was measured with the aircraft's inertial navigator. This technique has been employed successfully in other studies of volcanic plumes (Radke, Hobbs, and Stith 1976; Stith, Hobbs, and Radke 1978); given steady-state emissions, it yields good results when the atmospheric stability is neutral to stable and in moderate winds.

Most of the particles in the plume from Mount Erebus were approximately 0.1 micrometer in diameter (Radke in press). For particles greater than 1 micrometer in diameter, the plume and ambient samples were indistinguishable.

Estimates of the emission fluxes of various materials from Mount Erebus as well as from other volcanoes are shown in the table. The data for White Island, St. Augustine, Kverkfjol, and Mt. St. Helens were collected by members of the University of Washington's Cloud and Aerosol Group (see, e.g., Hobbs et al. in press; Stith et al. 1978) using instruments and techniques similar to those used in the present study. The Mt. Etna data were deduced by Zettwoog and Haulet (1978) from correlation spectrometer measurements. The measurements of Faivre-Pierret (1979) and Polian and Lambert (1979) were obtained by using treated filters at the crater rim and by visual estimates of the vent emission velocity.

The sulfur gases emitted from Mount Erebus were almost entirely sulfur dioxide (SO_2). On the flights for which fluxes estimates were made, the SO_2 emissions ranged from 0.4 to 1.8 kilograms per second (or an average of 40,000 tons per year expressed as sulfate). The corresponding particle fluxes ranged

Fluxes of emissions from Mount Erebus compared with fluxes of posteruptive emissions from other volcanoes

Volcano	Date	Flux of sulfur dioxide (kilograms per second)	Flux of particulate sulfate (kilograms per second)	Total flux of particles (number per second)	Reference
Mount Erebus	5 Nov 1980	1.80	—[a]	3.4×10^{16}	this study
	8 Nov 1980	0.45	—	1.2×10^{16}	this study
	14 Nov 1980	0.40	0.06	6.6×10^{15}	this study
	1978	0.019	—	—	Faivre-Pierret 1978
	1978	0.02	~0.001	—	Polian and Lambert 1979
White Island (New Zealand)	15 Oct 1980	1.75	—	4×10^{16}	this study
St. Augustine (Alaska, USA)	22 Apr 1977	0.3	—	6.0×10^{15}	Stith et al. 1978
Mt. Etna (Italy)	May 1979	12–14	—	—	Zettwoog and Haulet 1978
Kverkfjol (Iceland)	25 Jun 1980	0.03	—	6×10^{14}	this study
Mt. St. Helens (Washington, USA)	Sep–Dec 1980	0.1–40	0.1–1	4×10^{9} – 4×10^{17}	Hobbs et al. in press

[a] Dashes indicate not determined or unknown.

from 6.6 × 10^{10} to 3.4 × 10^{11} per second. Using the measured plume characteristics for 14 November 1980, the sulfate aerosol flux, derived from the filter samples, was estimated at 0.06 kilograms per second (or 2,000 tons per year).

My estimates of the sulfur emission fluxes from Mount Erebus are substantially greater than estimates by Faivre-Pierret (1978) and by Polian and Lambert (1979). Polian and Lambert estimated that .001 ton of sulfate [SO_2 + particulate sulfate (SO_4)] is emitted by Mount Erebus each year. Since the estimated total sulfate budget for Antarctica is 130,000 to 200,000 tons per year (Boutron personal communication; Shaw 1980), Polian and Lambert concluded that the emissions from Mount Erebus were unimportant in the sulfate budget of Antarctica. Obviously this conclusion must be reexamined in the light of my measurement of 42,000 tons per year of total sulfate emissions from Mount Erebus. If my measurements are representative, then as much as 32 percent of the antarctic total sulfate budget could be provided by Mount Erebus.

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Biogenic nuclei involvement in clouds over the Ross Ice Shelf

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The antarctic coastal clouds that form as a result of advection of marine air over the Ross Ice Shelf were investigated during October–November 1980. Measurements of the spatial and temporal distribution of Aitken and cloud condensation nuclei concentration in the subcloud layer have been reported elsewhere (Saxena 1981; Saxena and Baier 1981). This article presents the results of analysis of the chemical composition of the cloud water.

Samples of the cloud water were collected at around 75°53'S 172°20'E during a flight of the LC-130 in November 1980. A semicylindrical Teflon probe, 45.7 centimeters long and having an outside diameter of 3.2 centimeters, was projected through the sextant hole in the cockpit. The probe projected well beyond the surface boundary layer at the aircraft's cruising speed. The supercooled water droplets froze upon impact on the Teflon probe, enabling collection of cloud water in a solid phase (in a clear plastic bag). Prior to sampling, the probe was thoroughly rinsed with distilled, deionized water and dried.

The cloud water samples were analyzed with a Perkin-Elmer infrared spectrophotometer, an electron microscope, and an X-ray energy dispersion spectrometer. An algae grew on cloud water allowed to stand at 20°C under diffused sunlight for 4 weeks. An electron micrograph of this algae is shown in figure 1 (top). Also shown (figure 1, bottom) is the X-ray energy-dispersive analysis of the specimen. For the analysis, the water was allowed to dry on the face of a scrupulously cleaned germanium internal-reflection prism. The right-hand peak is characteristic of germanium. Elemental composition consisted of aluminum, silicon, sulfur, chlorine, and potassium. The abundance of silicon and potassium was about the same; sulfur apparently was the most abundant. Mount Erebus, an active volcano, is the only natural source of sulfur on the Antarctic Continent. Previous findings (Cadle et al. 1968) have led to the hypothesis that the sulfate particles originate in the Junge sulfate layer, and that stratospheric-tropospheric exchange brings them into the lower troposphere where they may get involved in the process of cloud formation.

Figure 2 (top) shows the rings formed by the residue submicron particles contained in the cloud water. Within each ring there are several submicron particles. Elemental composition of these particles may differ slightly, but an average representation can be worked out. Figure 2 (bottom) shows this average composition; the various peaks in the figure indicate the presence of sodium, silicon, phosphorous, sulfur, chlorine, potassium, and calcium.

Some tentative conclusions can be drawn from these analyses. The algae seen in figure 1 as fibrous and sheet-like matter can be identified as planktonema lauterbornii. The growth of an algae in "clean" antarctic cloud water, sampled through direct aircraft penetration with utmost care to avoid contamination, warrants further investigation because it indicates the presence of biogenic material in antarctic clouds. As reported earlier (Saxena 1981), infrared absorption spectra of the cloud water specimen have consistently indicated the presence of the proteinaceous matter.

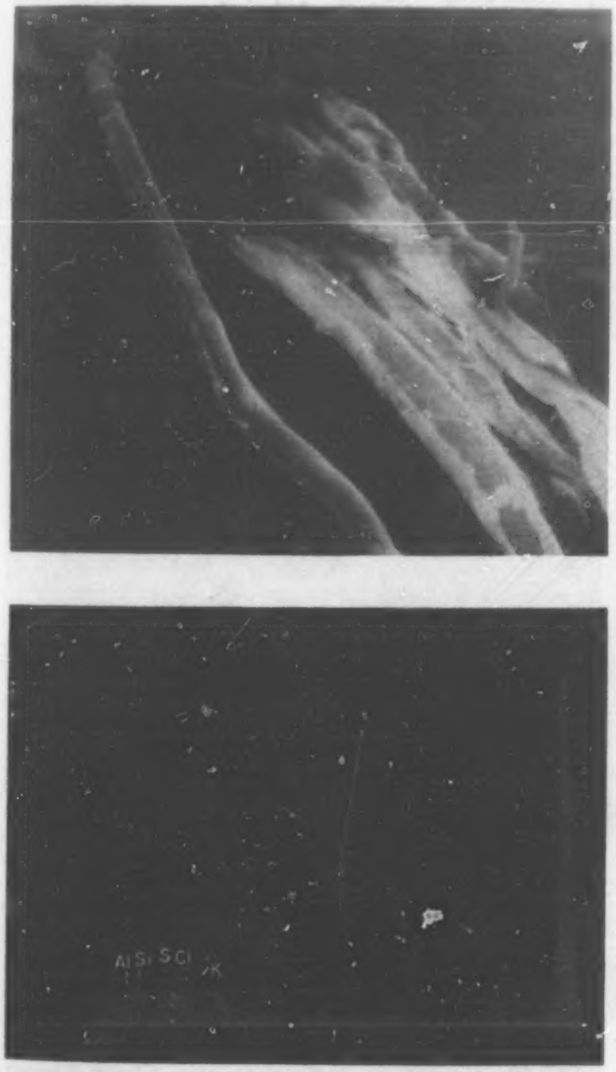

Figure 1. Top: Electron micrograph of algae that grew in antarctic cloud water collected through direct aircraft penetration, November 1980, around 75°53'S 172°20'E. Bottom: X-ray energy-dispersive spectrum of the sample shown at left. Peaks indicate the presence of aluminum (Al), silicon (Si), sulfur (S), chlorine (Cl), and potassium (K). The end peak is characteristic of germanium.

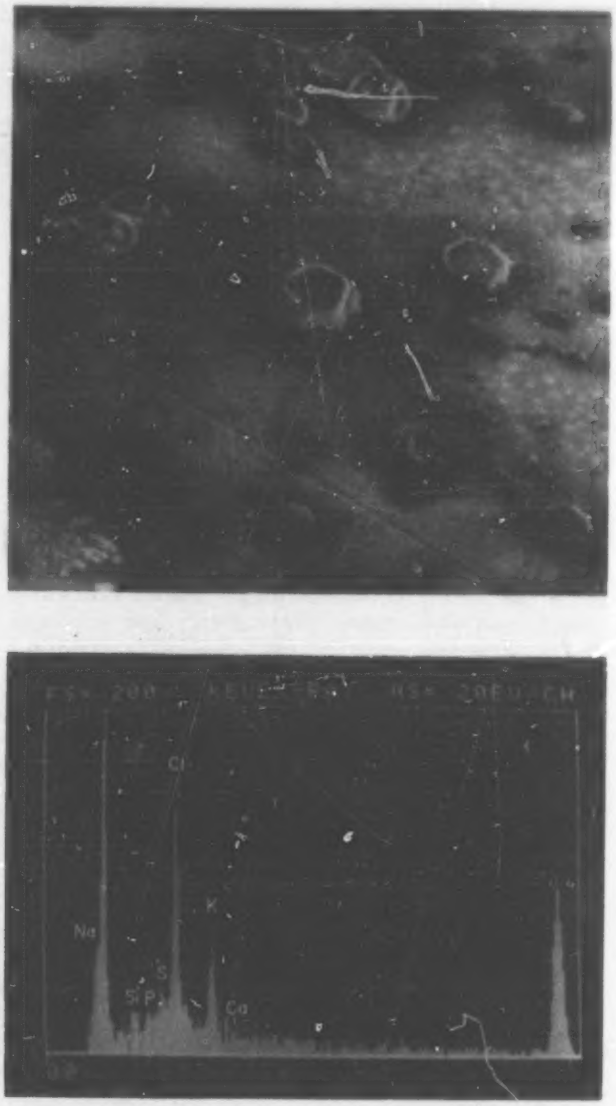

Figure 2. Top: Electron micrograph of the desiccated cloud water sample on the face of a germanium internal-reflection prism. Submicron particles are clustered around rings. Bottom: Typical X-ray energy-dispersive spectrum of a submicron particle shown at left. Contrast this with figure 1 (bottom). Peaks show the presence of, and indicate the relative abundance of, sodium (Na), silicon (Si), phosphorous (P), sulfur (S), chlorine (Cl), potassium (K), and calcium (Ca).

Evidence presented in figure 2 indicates that potassium and chlorine are relatively more abundant than sodium, and that the major ionically bonded salt in the cloud water is potassium chloride rather than sodium chloride. It is well understood that potassium chloride is enriched inside biological cells. These three pieces of evidence seem to confirm that cloud condensation nuclei of biogenic origin, such as those derived from plankton in the southern ocean, actively participate in the process of cloud formation over the Ross Ice Shelf. Frequently, these clouds produce snow. The biogenic nuclei may be initiating the condensation-freezing mechanism that helps these clouds precipitate. Previous studies (Schnell and Vali 1976; Vali et al. 1976) have indicated that biogenic nuclei exhibit good ice-nucleating activity.

Precipitation in the Southern Hemisphere (e.g., New Zealand) is known to be more nutrient-laden than that in the Northern Hemisphere. MacIntyre (1974) has discussed the recipe for rainwater for a small town on the New Zealand coast. The biological material in the precipitation samples represented one thousand times the amount of organics normally present in seawater. The processes by which this material finds its way into the atmosphere are still not understood, and heretofore there has been no report of plankton and algae in cloud water, though these things are an integral part of rainwater in New Zealand. Our measurements have indicated that the biogenic material, which may be derived from plankton, is present in the cloud water. This finding provides an insight into the relationship between macroscopic meteorology and microlayer oceanography. In the antarctic region, biogenic nuclei may be treated as a tracer for air masses that advect from the plankton-rich ocean onto the continent. Analysis of the transport processes of these nuclei clearly will require additional extensive measurements.

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Analysis of antarctic automatic weather station data from the western Ross Sea/Ice Shelf

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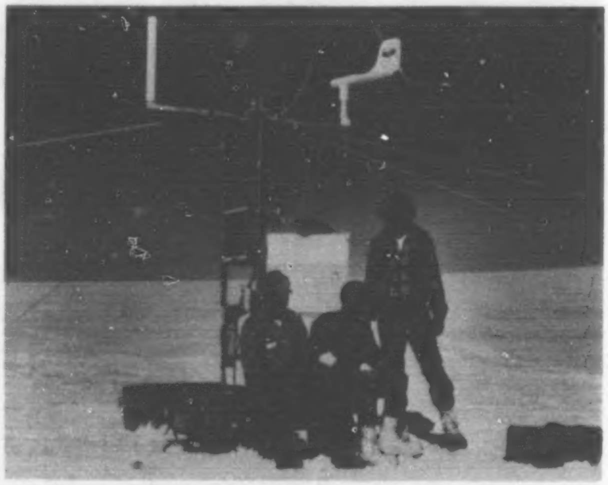

Figure 1. Automatic weather station "Jimmy" (2.5 nautical miles north-northeast of McMurdo). From left to right: C. S. Stearns and M. L. Savage, University of Wisconsin, and W. J. Thompson, Naval Postgraduate School.

In the Antarctic, where fewer than 30 manned stations lie scattered over vast regions and where surface visibility can decrease rapidly, endangering field parties and air operations, the automatic weather station is one way of collecting much-needed meteorological data.

Designed to operate under severe weather conditions automatic weather stations (AWS) currently provide reliable and accurate observations of surface pressure, wind, and temperature, for potential use in research on antarctic circulations. The data are available on a real-time basis (via satellite) to the Naval Support Force Antarctica weather center at McMurdo Station (figure 1).

A prototype station was installed at each of three antarctic locations in 1975–77. A second-generation station was deployed at each of seven locations during the 1978–79 austral summer. Five of these stations were located around McMurdo to provide warning of worsening weather conditions and to collect data for analyzing subsynoptic-scale circulations affecting the McMurdo operating area. In the summer of 1980–81, three stations were redeployed further east and southeast over the Ross Ice Shelf. During the 1981–82 season three new stations were added, bringing the total in the McMurdo area to eight stations (figure 2).

The data from the three prototype stations were analyzed at the Naval Postgraduate School to establish the credibility of the observations and their uniqueness to antarctic operations (Renard and Salinas 1977). Analysis of data from the second-generation stations (covering the period January 1979–February 1980) was completed recently (Scarbro 1982). Considerable statistical

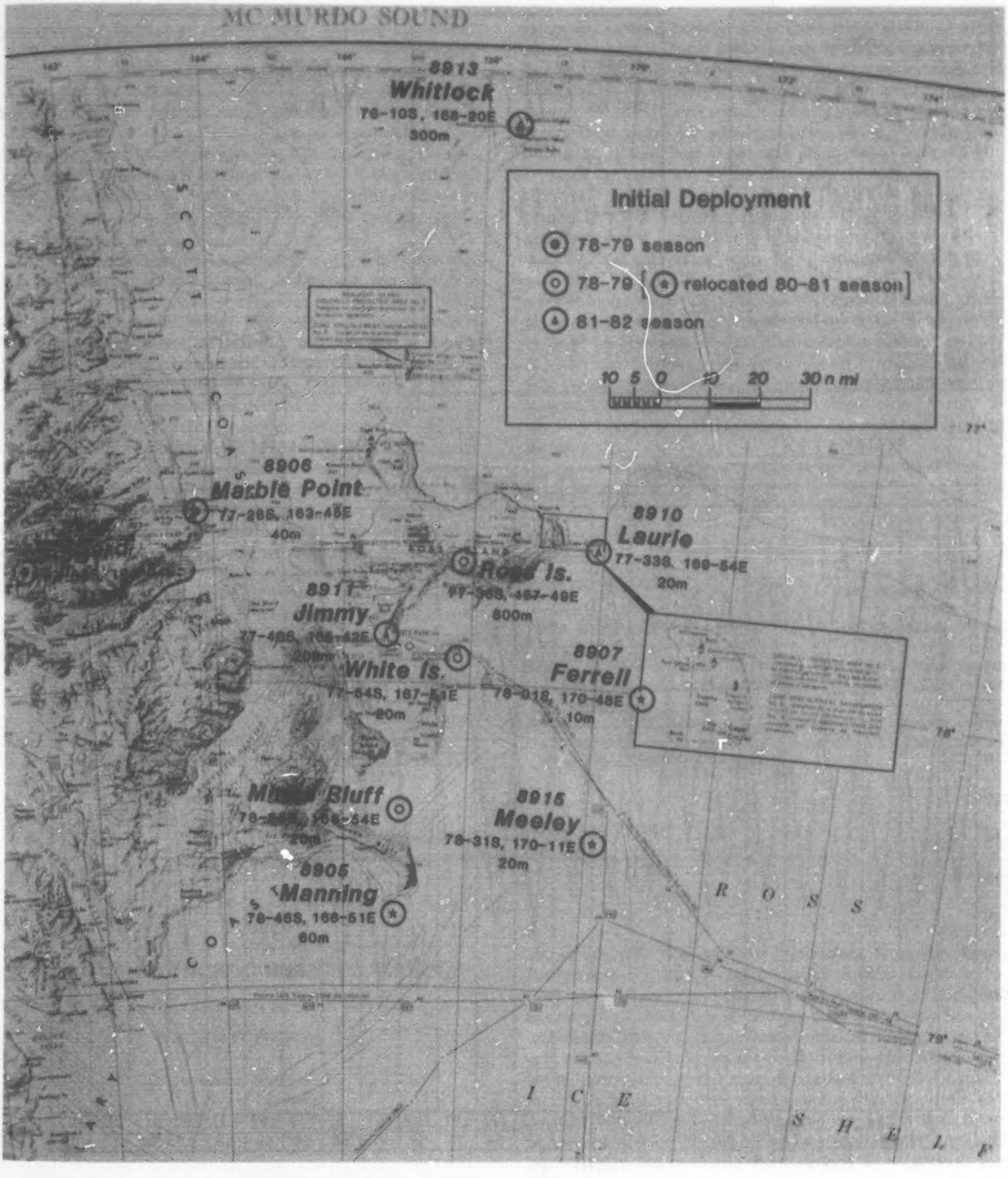
MC MURDO SOUND
8913
Whitlock
78-10S, 168-20E
300m
Initial Deployment
78-79 season
78-79 [relocated 80-81 season]
81-82 season
10 5 0 10 20 30 n mi
SCOTT COAST
8906
Marble Point
77-26S, 163-45E
40m
8910
Laurie
77-33S, 169-54E
20m
Ross Is.
77-36S, 167-49E
800m
8911
Jimmy
77-46S, 166-42E
200m
White Is.
77-54S, 167-51E
20m
8907
Ferrell
78-01S, 170-48E
10m
Minna Bluff
78-26S, 166-54E
20m
8915
Meeley
78-31S, 170-11E
20m
8905
Manning
78-46S, 166-51E
60m
ROSS ICE SHELF

Figure 2. Initial deployment sites for automatic weather stations in the McMurdo area.

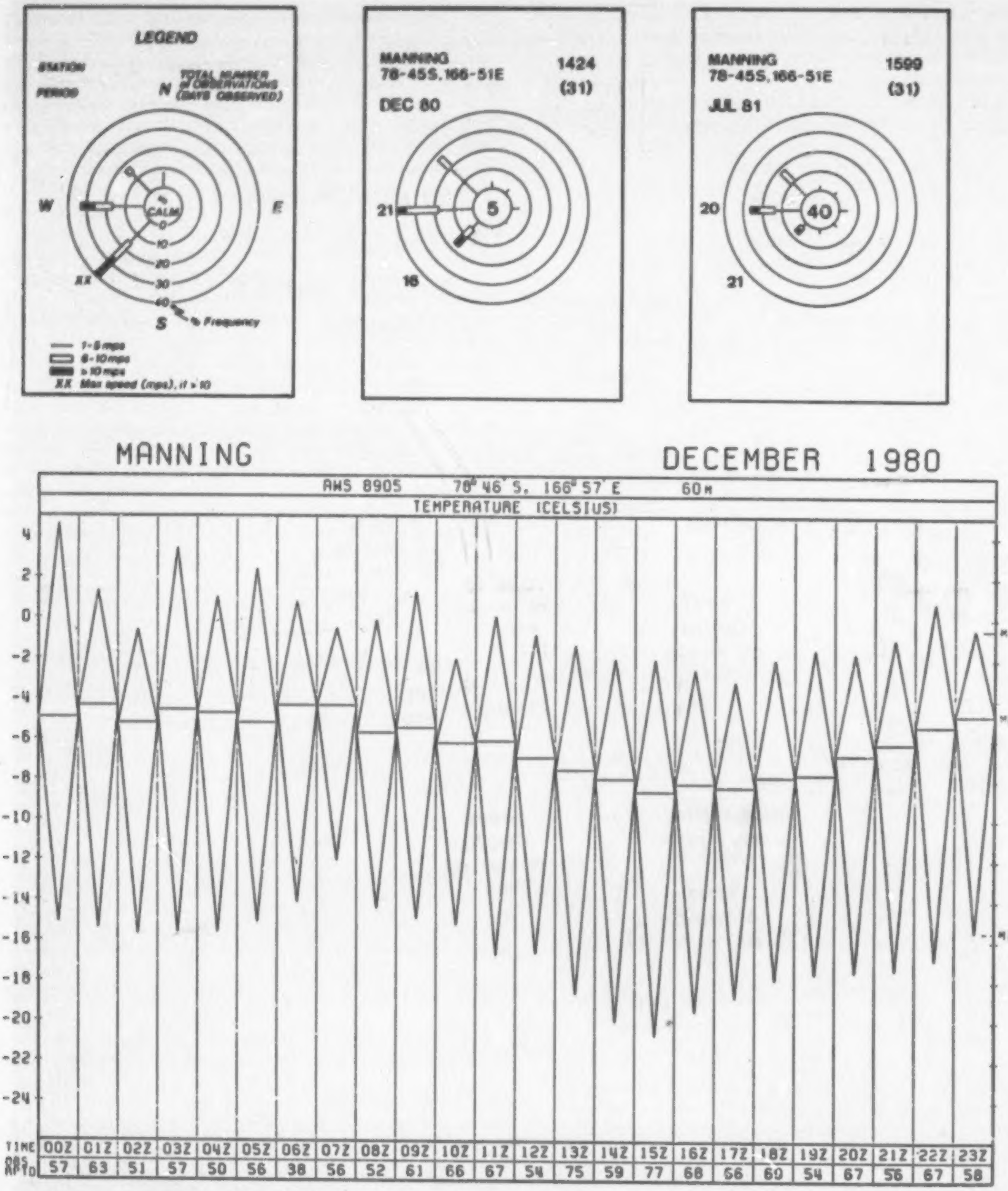

Figure 3. Automatic weather station Manning: wind roses for December 1980 and July 1981 and diurnal temperature statistics for December 1980.

processing of these later data was accomplished to enhance their potential for use in climatological and synoptic studies. There are some problems with the data as a result of mechanical failures that led to erroneous reports or shut the station down entirely. For those stations that did function, such as Asgard and Marble Point (figure 2), cross-comparisons with existing climatology from McMurdo give every indication that the data being transmitted were of excellent quality. Such data will be the basis for formulating a more extensive climatology for use in weather forecasting over the Ross Ice Shelf and McMurdo Sound areas.

Currently, data covering the period February 1980–December 1981 are being analyzed. During this period, the following McMurdo area stations were operational: Asgard, Marble Point, Meeley, Manning, and Ferrell. Completion of this analysis is being delayed because it is necessary to reprocess the data to include a number of pressure and wind corrections discovered during austral summer 1981–82 visits to the stations. Figure 3 presents samples of some of the derived climatological products for the Manning station for December 1980 (summer) and July 1981 (winter). Such observations of pressure, temperature, and wind are typical of the western Ross Ice Shelf area. Wind observations were made approximately twice an hour during both months. Wind direction and maximum wind speed during these months differed only in minor ways: mean wind speed in December (5.1 meters per second) was 50 percent higher than in July; wind steadiness was .80 in December and .71 in July; calms were much more common during July.

Diurnal variations in the high latitudes are also of interest. Figure 3 shows the diurnal temperature variation at Manning for December 1980. Keeping in mind that the local solar time is Greenwich mean time plus 11 hours, it can be seen that the maximum temperature occurs from 12 to 6 p.m. and the minimum from 2 to 4 a.m. There is a 4°C spread between the mean hourly high and low temperatures and an absolute range of nearly 25°C. Winter (not shown) has about the same absolute range and variation between mean diurnal high and low, but the mean temperature trend relates poorly to time of day in winter. Early indications from linear correlations of pressure, wind, and temperature data from the McMurdo weather center and from nearby AWS's (with and without time lag) indicate that the AWS data will be a useful supplement to the visual sightings from McMurdo in the effort to enhance short-period forecasting.

Part of the fiscal year 1982 effort included onsite visits to the automatic weather stations from mid-November through December 1981. Working out of McMurdo, W. Thompson provided assistance to the University of Wisconsin group in the annual maintenance, calibration, and setting up of new stations (Savage and Stearns 1982).

Visits to the Naval Support Force weather office made it possible to observe forecast procedures and to become familiar with some of the problems in issuing forecasts for flights in and out of McMurdo. Conversations with the duty forecasters suggest that the infomation received from outlying automatic weather stations often provide warning of an approaching change in weather conditions, in advance of indications on satellite imagery.

This work was supported in part by the National Science Foundation grant DPP 76-80165.

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Antarctic automatic weather stations

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Automatic weather stations (AWS) measure wind speed and direction, air temperature at a nominal height of 3 meters, and atmospheric pressure. Data are telemetered to polar-orbiting satellites every 200 seconds and are updated every 10 minutes. (For additional details, see Stearns and Savage 1981, and Savage, Stearns, and Teague 1981.)

Mike Savage and I, from the University of Wisconsin Department of Meteorology, were at McMurdo from 18 November to 17 December 1981, and William Thompson, from the Naval Postgraduate School, was there from 18 November to about 26 December—all of us in support of the AWS units. During the season, four additional stations were installed (at Siple Station; on Franklin Island; on Starr Glacier northeast of McMurdo; and east of Cape Crozier, Ross Island, on the Ross Ice Shelf), bringing to 13 the total number of operating AWS units. (See figure 1 for the locations of the new stations in the McMurdo area; also see the table for the coordinates and elevation of the 13 stations.) In addition, during the 1981–82 season, the Asgard, Manning, Marble Point, Dome C, and Byrd stations were serviced, the aerovanes that measure wind speed and direction were replaced with serviced units, and output data, as determined by the ARGOS test set, were checked against the measured pressure, air tempertaure, wind speed, and wind direction. For a complete description of the 1981–82 fieldwork and calibration results, see Savage and Stearns (1982).

Three AWS units were to be deployed in the Antarctic Peninsula region— on the Larsen Ice Shelf, on Butler Island, and at

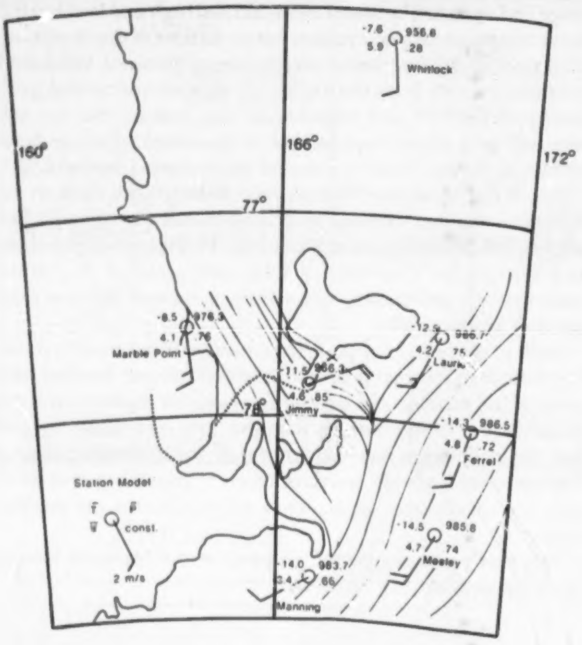

Figure 1. Map of the McMurdo area showing Simpson's 1917 streamlines and the resultant wind direction for February 1982 from the AWS units. Included is the monthly mean of air temperature (°C), station pressure (millibars), scalar wind speed (meters per second), and constancy of the wind. The barbs on the resultant wind arrow are for the resultant wind speed (meters per second). Stations Jimmy, Laurie, Whitlock, and Siple, were installed during the 1981–82 austral summer.

Sites, identification number, latitude, longitude, and elevation for 13 AWS units operating properly as of 1 February 1982

Site	ID	Location	Elevation (meters)
D-10	8901	66°42'S 139°50'E	267
Byrd	8903	80°00'S 120°00'W	1,530
Dome C	8904	74°30'S 123°00'E	3,280
Manning	8905	78°46'S 166°56'E	60
Marble Point	8906	77°26'S 163°45'E	120
Ferrel	8907	78°01'S 170°48'E	20
Asgard	8908	77°36'S 161°04'E	1,750
Siple*	8909	75°54'S 84°18'W	900
Laurie*	8910	77°33'S 169°54'E	20
Jimmy*	8911	77°48'S 166°42'E	200
Whitlock*	8913	76°05'S 168°20'E	300
Meeley	8915	78°31'S 170°11'E	20
D-57	8916	68°11'S 137°31'E	2,064

*New stations installed in November–December 1981.

Fossil Bluff—during 1981–82. However, on 18 November a strong wind damaged the two British Antarctic Survey (BAS) twin otter aircraft that were to be used, and the stations were not deployed. (It was just as well, because the AWS units were not operating properly and at that time the reason was not known. Later it was found that in reversing the leads to one wind vane, so that the wind direction was correct, the common connection to the anemometer was connected to the reference power supply instead of to the ground. The reference voltage was thus unsteady and uncertain.) The BAS subsequently deployed two units to Petite Rocks and to northern Adelaide Island.

Enough AWS units are now deployed in the McMurdo area so that observations of the mesoscale circulation can be made. Figure 1 shows the resultant wind direction and mean data for February 1982, the first full month of operation. Also shown in figure 1 are the streamlines obtained by Simpson (1919) in July 1917. The July 1981 data from Manning, Ferrel, and Meeley stations approximate the February 1982 resultant wind direction and speed. The resultant wind direction is in substantial agreement with Simpson's observations.

Disturbances such as a change in wind speed or direction are observed to propagate across the ice shelf. Figure 2 shows a change in wind speed and direction which moved from the south on 11 January 1982. Three stations were used to estimate the speed and direction of the disturbances. Using the arrival times of the wind direction maximum at Jimmy, Laurie, and Meeley sites gives a propagation speed of 6.2 meters per second and a direction of 180°. The direction is close to the observed wind direction prior to and after the event at Meeley and Laurie sites. The speed is slightly higher than the surface wind speed. The observed surface event probably is related to the atmospheric behavior within the boundary layer. The propagation speed and direction are uncertain because the timing error

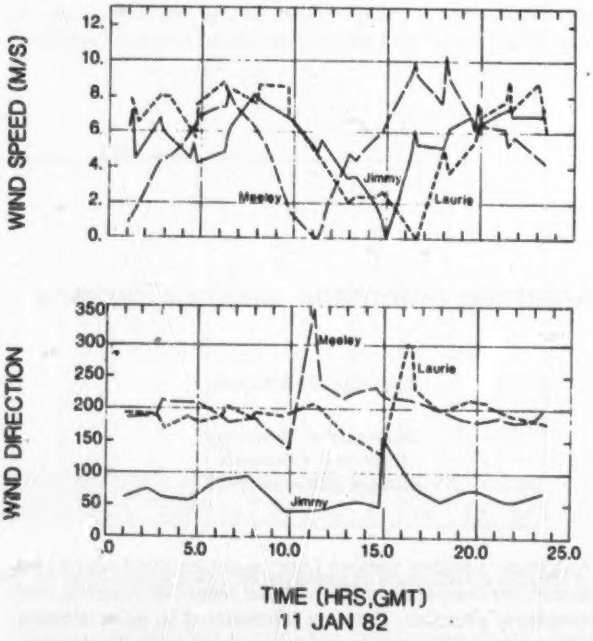

Figure 2. Wind speed and direction at Meeley, Jimmy, and Laurie sites, as a function of time of day, for 11 January 1982. The time differences between the wind direction maximum gave a propagation speed of 6.2 meters per second from 180°.

is never less than 10 minutes and may be more, depending on the time the satellite was available to receive the data transmission. The time interval from Meeley to Laurie site is 315 minutes, but can be in error by 10 minutes, or at least 3 percent. The wind direction and speed disturbance were not observed at Manning, but the data from Marble Point and Ferrel sites showed changes similar to those at Jimmy, Laurie, and Meeley sites. The air temperature and pressure time changes did not agree well with the wind speed and direction changes.

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Air chemistry and meteorology

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The objective of this research, both in Antarctica and during the trans-Pacific aircraft deployment operation, was to conduct a program of air chemistry studies related to meteorological exchange processes in the troposphere and lower stratosphere, especially in Antarctica. The atmospheric samples were collected by using the National Science Foundation's LC-130 (A/C 131) and McMurdo-based helicopters. The second season of a two-season field program of helicopter vertical profiling has now been completed. Analyses have included study of the halocarbons F-11 ($CFCl_3$), F-12 (CF_2Cl_2), methyl chloroform (CH_3CCl_3), and carbon tetrachloride (CCl_4); nitrous oxide (N_2O); the C_2 hydrocarbons ethane, ethylene, and acetylene; and carbon dioxide (CO_2). Helicopter sampling missions emphasized vertical profiles that permit a detailed examination of exchange processes between the land surface, the boundary layer, the free troposphere, and the stratosphere. The data collected during the second field season have not yet been evaluated in detail. However, results of the first season trace gas profiles have been submitted for publication (Robinson et al. in press).

The 1981 continuation of our annual latitudinal gradient studies of atmospheric trace gases, begun in 1976, was accomplished by collection of air samples on board A/C 131 from California through Hawaii, Pago Pago, American Samoa, and Christchurch, New Zealand, to McMurdo Station. Ground samples also were collected at South Pole Station and at Mt. John, New Zealand. Most of these samples were air freighted to the Washington State University (WSU) laboratories for immediate analysis.

Helicopter air-sampling flights began 21 October 1981 and continued until 3 December 1981. In all, 18 flights were made; on most flights 12 samples were collected between 30 and 3,000 meters. The samples were analyzed, at least in triplicate, for F-12, F-11, CH_3CCl_3, CCl_4, and N_2O in a laboratory at McMurdo Station.

The 1981 data have been entered into a computer data file and quality-control checks have been completed, but interpretation of results has not been completed. However, the 1981 helicopter flight profiles are expected to increase the size of the database for statistical use in classifying the different concentration profile types according to the synoptic weather situations. In this article we discuss some results of the 1980 helicopter vertical profiling which are supported by preliminary review of the 1981 data set.

As we noted previously (Robinson and Cronn 1981), the concentration gradients observed in the helicopter profiles are frequently larger than the variability observed between duplicated samples, so that the profiles observed are indicative of the changing synoptic conditions in the antarctic atmosphere at McMurdo during the sampling program.

The data have been combined and averaged in several different ways in order to characterize identifying patterns that can explain the development of the different kinds of profiles. Figure 1 shows the 13-flight average profiles for the five trace gases F-12, F-11, N_2O, CCl_4, and CH_3CCl_3. The profiles are similar in two ways: (1) the lowest concentration of each compound is in

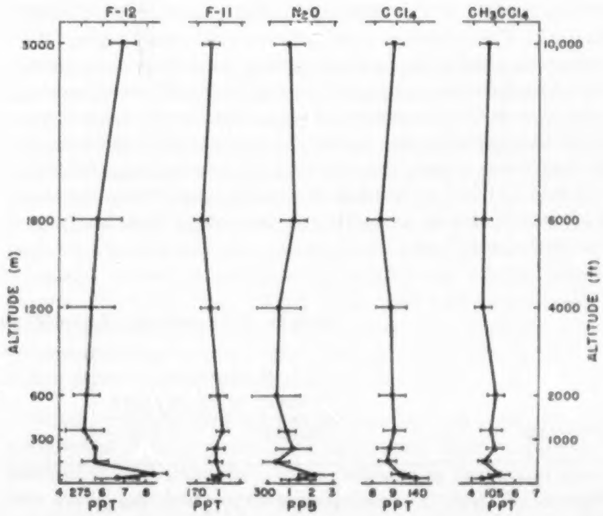

Figure 1. Average concentration profiles for F-12, F-11, N_2O, CCl_4, and CH_3CCl_3 for 13 helicopter flights over the Ross Ice Shelf between 31 October and 4 December 1980.

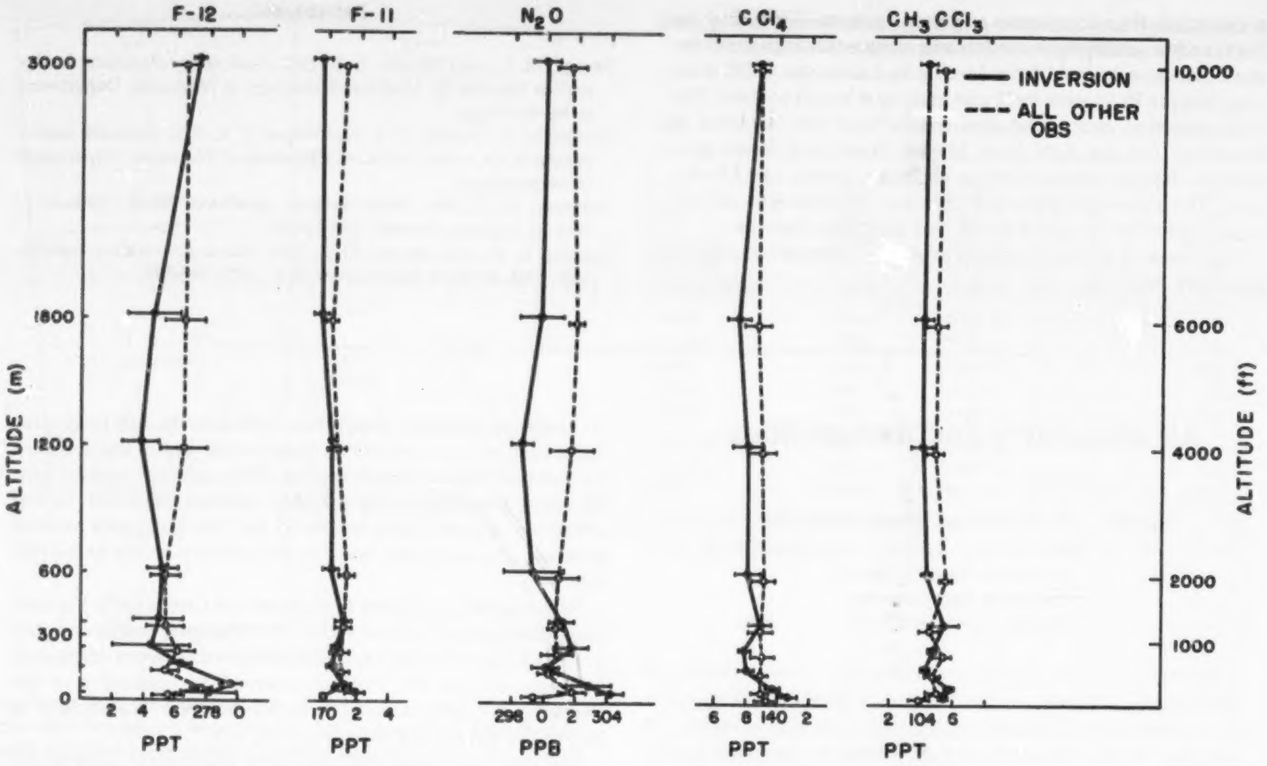

Figure 2. Comparison of average concentration profiles for five flights with low-level inversions (30–150 meters) and remaining eight profiles.

midprofile (between 360 and 1,800 meters), and (2) the highest concentrations occur generally within the surface layer (360 meters for F-11 and 30–60 meters for the other four compounds).

Separable sets of chemical-concentration profiles are obtained when the average of the five profiles having a temperature inversion between 30 and 150 meters is compared with the average profile of the eight remaining noninversion profiles (figure 2). The inversion profiles have significantly higher concentrations statistically in the boundary layer (30 meters and 60 meters) relative to midprofile levels, while the noninversion cases do not. Concentrations are also significantly lower statistically through the upper part of the profiles (600–3,000 meters) for the inversion cases than for the noninversion cases for N_2O, F-11, and CH_3CCl_3. The table shows the results from the two-stage statistical tests comparing these averaged profiles (inversion and noninversion).

The results of the statistical comparison of two similar separations of profiles based on two other criteria are also presented in the table. One separation criterion is between profiles having large (≧14.5°C) or small (≦10°C) lapse rates through the upper part of the flight profile (240–3,000 meters). Another separation criterion is between profiles collected when the upper winds at McMurdo were from the northwest or the southeast. These pattern differences are the result of synoptic-scale weather influences. The hypothesis for explanation of these features will be presented in detail elsewhere (Robinson et al. in press). Briefly, profiles having higher concentrations aloft are believed to reflect more recent transport of an air mass from midlatitudes. The lower concentrations are considered to be cases of "older" antarctic air masses, because a longer residence time would be needed to bring about a greater dilution with stratospheric air. The combined 1980 and 1981 data sets will be used

Results of the analysis of covariance for three separations of flight profiles

Compound	Surface level Inversion vs. no inversion		Lapse rate ≧ 14.5°C vs. ≦ 10°C		Upper winds NW vs. SE	
	Parallel?	Apart?	Parallel?	Apart?	Parallel?	Apart?
N_2O	yes	yes	yes	no	yes	no
F-12	yes	no	yes	no	yes	yes
F-11	yes	yes	yes	no	yes	yes
CH_3CCl_3	yes	yes	yes	yes	yes	no
CCl_4	yes	no	yes	no	yes	yes

to explore comparisons of the synoptic situations and air-mass trajectories with the profiles for confirmation of the hypothesis of proportional mixing of stratospheric air and midlatitude air over Antarctica.

The fieldwork was supervised by D. Cronn (9 November to 10 December 1981), with field support by Robert Watkins (18 October to 10 December 1981). Winai Nutmagul performed sample analyses at WSU, and W. Lee Bamesberger performed computer analyses. The VXE-6 air crews on both the LC-130 and the helicopters provided excellent support through conscientious performance of the flight plans. Special recognition is due National Science Foundation and Antarctic Services, Inc., personnel for construction of appropriate laboratory space at McMurdo Station. This research was supported by National Science Foundation grant DPP 79-21003.

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Geophysical monitoring for climatic change, Amundsen-Scott South Pole Station, 1981

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The objective of the National Oceanic and Atmospheric Administration (NOAA) Geophysical Monitoring for Climatic Change (GMCC) program is to monitor, through continuous measurements, the background concentrations of various atmospheric trace constituents. GMCC maintains four baseline research observatories in remote areas of the world: Point Barrow, Alaska; Mauna Loa, Hawaii; Cape Mataula, American Samoa; and Amundsen-Scott South Pole Station, Antarctica. Measurements obtained at these stations will be used to determine whether the gases or particulates introduced into the atmosphere by natural causes or human activities are significant enough to affect climate, and if so, to determine the anthropogenic impact related to those changes (DeLuisi 1981; Herbert 1980; Mendonca 1979).

The GMCC observatory at the South Pole continued normal operations during the 1980–81 season. The clean air facility, approximately 90 meters upwind from the main station, houses the GMCC program. The program involves: (1) continuous monitoring of carbon dioxide, solar radiation, aerosols, meteorology, and surface ozone; (2) discrete measurements of total ozone, halocarbons, turbidity, carbon-14, and carbon 12/13; and (3) various cooperative programs from universities and other government agencies. The measurements will be used to determine how the air masses over Antarctica receive, store, and remove gases and aerosols placed into the atmosphere at other locations on the Earth (Bortniak and Mendonca 1980). During the period November 1980 to November 1981, the GMCC program at the South Pole was operated by Cynthia McFee, Lt(jg) NOAA Corps (chief observer), and Edward R. Green (electronics engineer).

Measurements made by the GMCC program are briefly summarized here.

Carbon dioxide. Continuous carbon dioxide (CO_2) measurements were made with a nondispersive infrared gas analyzer URAS 2T. Discrete samples using 0.5-liter flasks were alternately taken through the analyzer system and aspirated by hand. A portable pressurizer pack, received on the first South Pole air drop, replaced the hand-aspirated method on 21 July 1981.

Aerosols. A General Electric condensation nuclei counter was used to make continuous measurements of Aitken nuclei concentrations. A Pollak counter, used as a calibration standard, made discrete measurements twice a day. The four-wavelength nephelometer successfully monitored aerosol light-scattering properties for the second nonconsecutive year.

Meteorology. Continuous measurements of wind, air and snow temperatures, barometric pressure, and moisture were taken.

Solar radiation. During the austral summer continuous measurements were taken of direct solar irradiance and global irradiance. Direct solar irradiance was measured with an Epply normal incidence pyrheliometer on an equatorial mount. Global irradiance was measured with four Eppley global pyranometers having quartz, GG-22, OG-1, and RG-8 filter domes and with an ultraviolet (UV) pyranometer. The GG-22 and UV pyranometers were discontinued after February 1981. A manually aimed pyrheliometer fitted with a filter wheel (quartz, OG-1, RG-2, and RG-8 filters) was used to make discrete measurements three times a day. A hand-held sunphotometer was used to make discrete measurements of turbidity at 380- and 500-nanometer wavelengths.

Ozone. A Dasibi ultraviolet ozone monitor was used to make continuous measurements of surface ozone. Total ozone measurements were taken three times daily during the austral summer using a Dobson spectrophotometer. During the austral winter, focused moon observations were made when possible.

Halocarbon. Samples of outside air were collected in 300-milliliter steel cylinders to be analyzed in Boulder, Colorado, for concentrations of trichlorofluoromethane (F-11), chlorodifluoromethane (F-12), and nitrous oxide (N_2O). This was done weekly during the austral summer and bimonthly during the austral winter.

Carbon 12/13. Outside air was collected monthly in 10-liter stainless steel cylinders and analyzed at the U.S. Geological Survey in Denver, Colorado. This program began in January 1981.

Instrument control and data acquisition system (ICDAS). All GMCC instruments that are run continuously are controlled by, and their data fed into, ICDAS. ICDAS consists of the following components: Data General NOVA 1220 minicomputer, Xerox multiplexer-digitizer, Wangco tape drive, chronolog digital clock, and a teletype. The data are collected, scaled, and written onto magnetic tape on a real-time basis.

The GMCC program at the South Pole is operated by the Air Resources Laboratory of NOAA with support from the National Science Foundation. For additional information and a review of all activities since 1972, see GMCC program summary reports 1–10. In addition to data acquisition and archival work, the GMCC organization is actively involved in atmospheric research. Data analysis and interpretation and research publications are part of the continuing work performed at the Environmental Research Laboratories located in Boulder, Colorado.

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Upper atmosphere studies

Measurement of ionospheric electron columnar content changes over McMurdo Station

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To study the effects of ionospheric scintillations on the tracking of navigation satellites in the southern polar regions, Applied Research Laboratories, University of Texas at Austin, has collected ionospheric electron columnar content change data at McMurdo, from 1979 to the present. Applied Research Laboratories operates the satellite tracking station for Navy Navigation Satellites (NNS's) at McMurdo and, in addition, collects ionospheric data with a special piece of hardware called the refraction offset generator (ROG). During this period a large amount of data about solar maximum was collected. This information is an important tool in studying the morphology of the ionospheric scintillations in the southern polar region.

The NNS's transmit coherent radio signals at 150 and 400 megahertz. The two signals are used to remove ionospheric effects from navigation data. This can be done because of the dispersive nature of the ionosphere. The refraction offset generator retrieves this ionospheric information and provides a measure of the change in the number of electrons along the line of sight ($\dot{N}_{LOS}$) as the satellite passes over McMurdo in a 1,000-kilometer orbit. The absolute number of electrons along the line of sight is not obtained unless an additional reference measurement is provided.

The ROG satellite tracking schedule has been designed so that comparisons can be made with other data sources. For most of 1979, four passes per day were tracked in order to ensure a continuous database. Beginning in 1980, the basic schedule was changed to the recording of four passes per day on Tuesdays, Wednesdays, and Thursdays and a more intense schedule (8–12 passes per day) on Regular World Days.* Approximately 2,500 passes have been recorded during the 3-year period 1979–1981, with a fairly uniform time-of-day distribution.

The $\dot{N}_{LOS}$ data are digitized and analyzed at Applied Research Laboratories to provide information regarding the morphology of radio wave scintillations in the southern polar ionosphere. Small spatial scale variations in electron density can cause rapid phase and amplitude variations (scintillations) in the radio waves and thus can disrupt the satellite tracking channel. A knowledge of the morphology of these scintillations will enhance understanding of the processes in the polar ionosphere.

Analysis of the data is still in the early stages, but an example of ROG data for one satellite pass is shown in figures 1 and 2 to illustrate the type of information these data provide. The polar diagram in figure 1 gives the track of the line-of-sight ionospheric intercept at 350 kilometers, the altitude at which most of the ionospheric electrons are concentrated. The data plot in figure 2 gives the change in electron columnar content (total number of electrons in a column of unit area) along the line of sight as the satellite passes over McMurdo. The data are plotted on a time axis with a time resolution of about 0.25

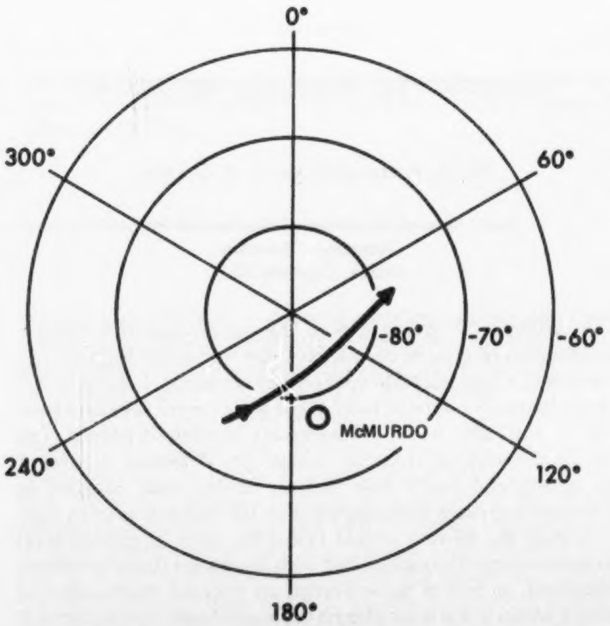

Figure 1. Line-of-sight ionospheric intercept track at 350 kilometers.

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*Regular World Days are the 3 days a month specified by the International Ursigram and World Days Service for international cooperation on solar and geophysical data collecting.

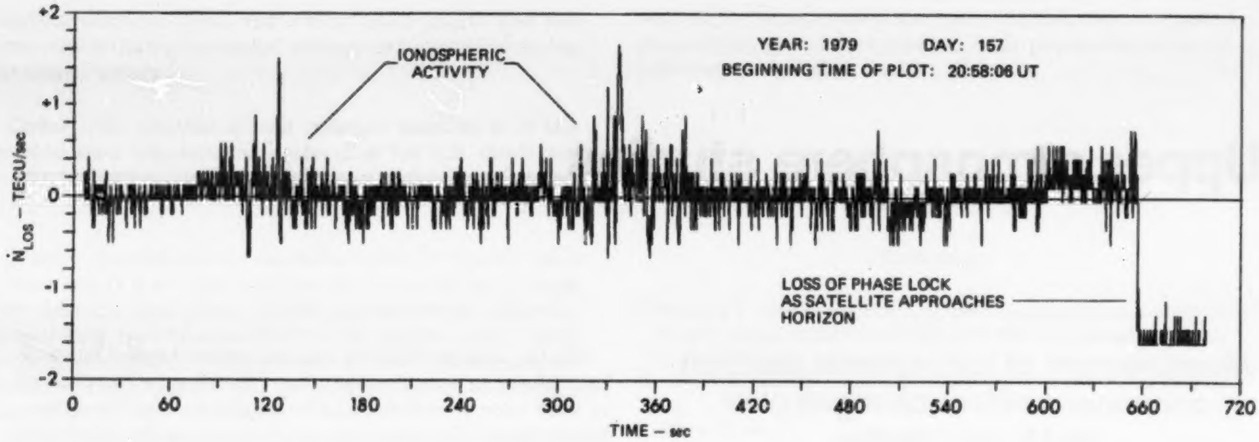

Figure 2. Example of data collected by the refraction offset generator.

second and data resolution of about 0.16 TECU per second (one TECU = 10^{12} electrons per square centimeter). These resolution values are determined by the digitizing sampling rate (4 hertz) and can be decreased, if necessary, by redigitizing the data at a higher sampling rate. The ionospheric intercept computed from the known satellite position provides a horizontal spatial resolution of 1–2 kilometers.

This data sample shows two regions (near 120 and 360 seconds) where the rate of change of electrons is much larger than usual, while the remainder of the sample shows a rate of change close to an ambient level. We hope to correlate these regions of high activity, on a statistical basis, with identifiable geophysical features such as active aurora or geomagnetic storms.

The data collection at McMurdo is an ongoing effort; the data are put on cassette tapes and shipped out several times a year. The digitizing and analysis at Applied Research Laboratories began recently, and statistical results for the 1979 and 1980 data are expected shortly.

Cosmic ray intensity variations

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In addition to giving rise to the continuous and varying modulation of galactic cosmic rays, the Sun emits high-energy particles (> 1 gigaelectron volt) on rare occasions. Guided by the interplanetary magnetic field, these solar cosmic rays find their way to the Earth when the necessary conditions prevail. The Bartol network of antarctic cosmic ray detectors located at McMurdo and South Pole Stations record solar particles as intensity increases superimposed on the ambient galactic flux.

During the 45-year period 1936–1980, only 32 ground-level enhancements (GLE) associated with large solar flares have been observed. In two of these events, an unusual combination of shock waves in the solar plasma led to acceleration of particles in interplanetary space (rather than in the vicinity of the Sun). During 1981, two additional GLE events were recorded, one of

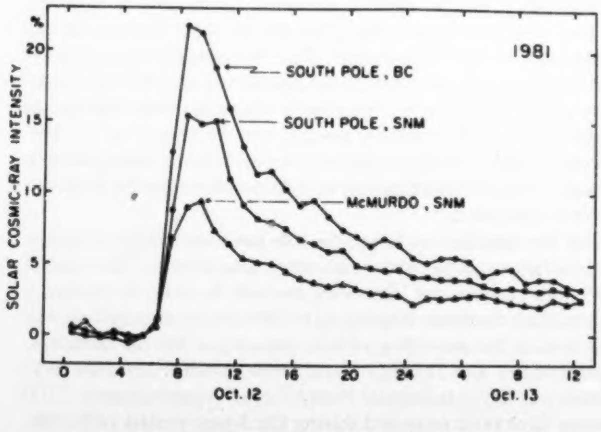

Figure 1. Enhancements in the nucleonic intensity recorded in Antarctica (McMurdo and South Pole Stations) associated with a solar flare on 12 October 1981. SNM refers to the conventional sensor, the so-called "super neutron monitor" array. BC, or "bare counter" responds to slightly lower primary energies and thus is more sensitive to solar cosmic rays. For galactic cosmic rays, the intensity changes in SNM and BC at South Pole are always identical.

which could not have been unambiguously identified prior to the installation of the new so-called atmospheric neutron detector at South Pole Station.

The outstanding solar flare (importance 3B) that commenced at 1632 universal time on 10 April 1981 was associated with the heretofore undetectable GLE, which reached a peak magnitude of only 1 percent around 1900 universal time, although the heliographic location of the solar flare at 07°N 35°W was favorable for the propagation of particles from the Sun to the Earth.

On the other hand, the chromospheric eruption (importance 3B) that occurred on 12 October 1981 at 17°S 32°E, far from the base of the "garden hose" field line that connects the Sun with the Earth, produced a large GLE (figure 1). This event is barely compatible with the model we proposed some time ago (Duggal and Pomerantz 1973) that envisages a fast propagation region where energetic particles are transported by a still-unknown mechanism around a large portion of the solar circumference (up to about 90°). The onset of the enhancement at approximately 0645 universal time, just 28 minutes after the commencement of the solar flare, was almost simultaneous in the north and south polar regions. Preliminary calculations indicate that the spectrum of this event can be represented by a power law of the form $I = KP^{-\gamma}$, where K is a constant, P is particle rigidity, and $\gamma \approx 5.0$.

A quite different study of our measurements of the north-south asymmetry has revealed that there is a genuine 27-day variation (corresponding to the rate of rotation of the Sun about its axis), whereas shorter period peaks noted earlier in the power spectrum are not significant. Analysis of the relationship between north-south asymmetry and the component ($\vec{B}_\parallel$) of the interplanetary magnetic field parallel to the "garden hose" direction has been carried out. Figure 2 shows a superposed epoch analysis of the north-south asymmetry as derived from the cosmic ray flux recorded simultaneously at Thule and McMurdo. The key days (day zero) for the plots in this figure are characterized by large values of $\vec{B}_\parallel$, either toward or away from the Sun. The magnitude of the axial anisotropy clearly is related to $\vec{B}_\parallel$, and the intensity variation around the epoch day is repeated near ±27 days. Furthermore, the phase of north-south asymmetry depends on the direction of $\vec{B}_\parallel$. This analysis has confirmed our hypothesis that the origin of 27-day variations in the north-south anisotropy is the streaming caused by $\vec{B}_\parallel \times \vec{\nabla} n$ drift, where $\vec{\nabla} n$ represents the radial gradient of galactic cosmic rays.

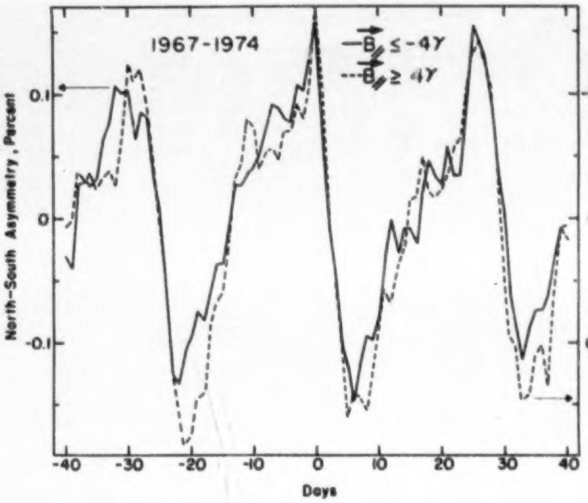

Figure 2. Superposed epoch analysis of the north-south asymmetry with respect to key days selected on the basis of the sense and magnitude of $\vec{B}_\parallel$, the component of the interplanetary magnetic field along the spiral "garden hose" direction. (a) $\vec{B}_\parallel > 4\gamma$ and (b) $\vec{B}_\parallel < -4\gamma$ ($\gamma = 10^{-5}$ gauss). The number of key days for the two plots are 363 and 465, respectively. The vertical scale on the right, which corresponds to epochs characterized by $\vec{B}_\parallel > 4\gamma$, has been inverted.

This work is supported by National Science Foundation grant DPP 79-23218.

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Correlative results from South Pole Station, 1981

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The importance of South Pole Station as a ground-based observatory for upper atmospheric and magnetospheric phenomena has gained increasing recognition during the past several years. While a few upper atmospheric experiments have operated throughout the history of the station, the 1981 season saw a concerted effort to expand the program to provide coordinated observations with a variety of instruments.

The significance of South Pole Station lies in its location with respect to the auroral oval. Because of the approximately 15-degree offset of the dipole axis with respect to the geographic axis, the station appears to rotate in a circle just inside the average oval position. Since the oval delineates the boundary between closed dipolar field lines and the long lines that trail back from the polar cap into the magnetotail, South Pole Station is a unique location from which to see effects occurring in both regions and to observe the transition from one to the other.

The current emphasis of the program is on studies of the dayside cusp, a funnel-shaped feature of the magnetosphere

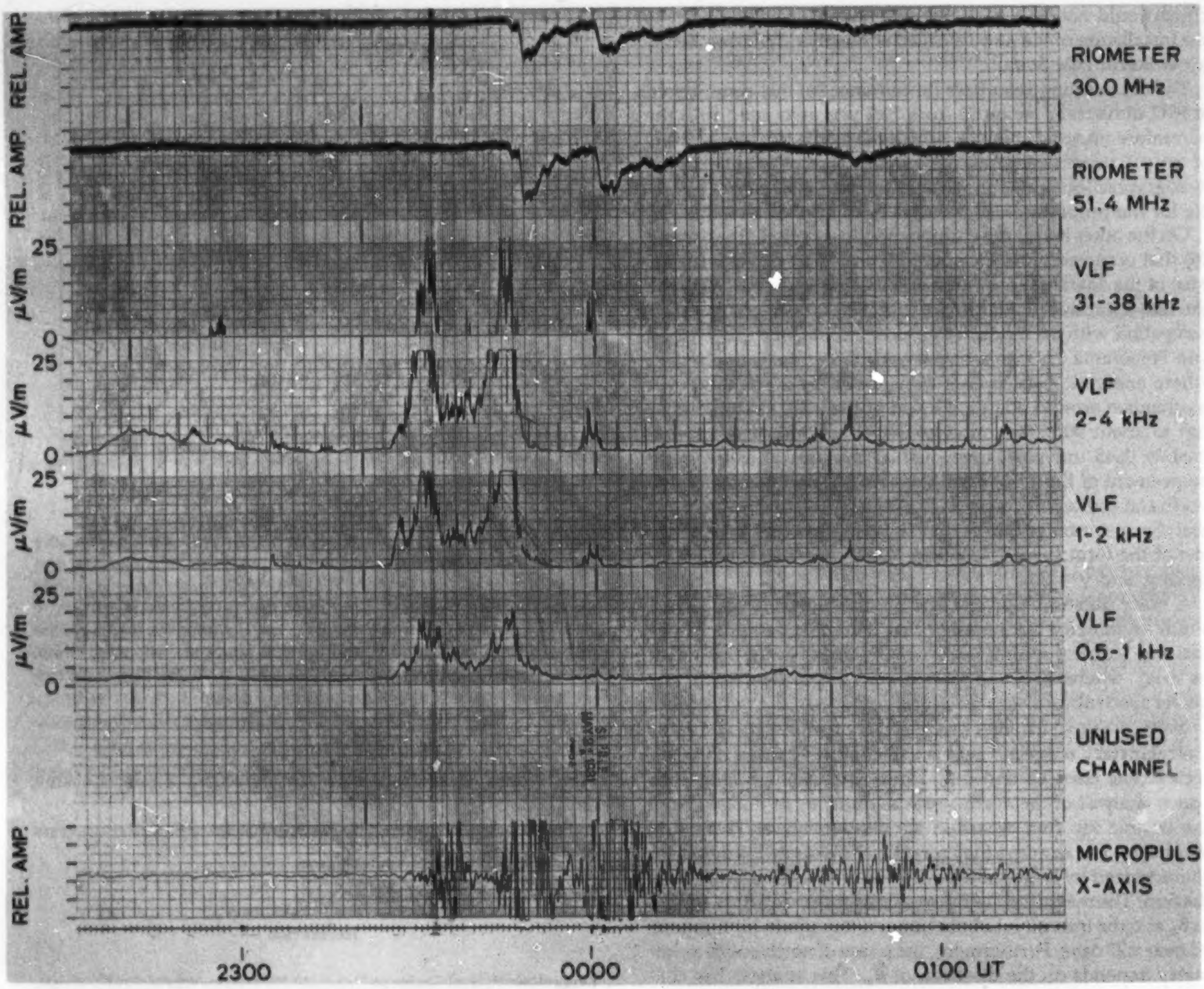

Figure 1. South Pole Station chart record showing substorm activity. Three possible onsets are seen, with correlation of hiss cutoff, riometer absorption, and micropulsations onset evident. REL. AMP. = relative amplitude; μV/m = microvolts per meter.

formed at the conjunction of the swept-back polar cap field lines and the closed dayside lines. Satellite studies (Frank and Ackerson 1971; Heikkila and Winningham 1971) have shown that the cusp is a region where solar wind plasma can penetrate directly into the magnetosphere and reach low altitudes. Under average oval conditions, South Pole Station rotates beneath the cusp at geomagnetic noon each day, making it one of the few locations in the world where routine ground observations of this region can be made.

During 1981, narrowband very-low-frequency (VLF), riometer, and micropulsations channels were recorded simultaneously on an 8-channel Sanborn chart recorder to provide a correlative data format. The remainder of this article discusses three examples of correlated phenomena seen at South Pole Station during this period.

Figure 1 is a portion of the chart record for 20–21 May showing a substorm event. The substorm is a poorly understood process in which large amounts of energy are released suddenly from the tail of the magnetosphere and shower down as particles into the ionosphere in the auroral oval. In figure 1, three instances of possible substorm onset are visible. In each instance, a broadband VLF hiss terminates in conjunction with the onset of strong micropulsations. In the latter two events, micropulsations onset and hiss cutoff also correspond to the beginning of cosmic noise absorption. These events indicate a close link between the process that produces VLF hiss, micropulsations, and the particle precipitation responsible for cosmic noise absorption.

Figure 2 shows an excerpt from 4 April in which a strong lull in VLF noise level corresponds closely to a similar feature in the micropulsations. Measurement reveals that the impulsive changes at both ends of the micropulsations trail their VLF counterparts by about 75 seconds. Similar results were obtained for a number of other events in which impulsive micropulsations and VLF occurred together. Given these delay periods, it is

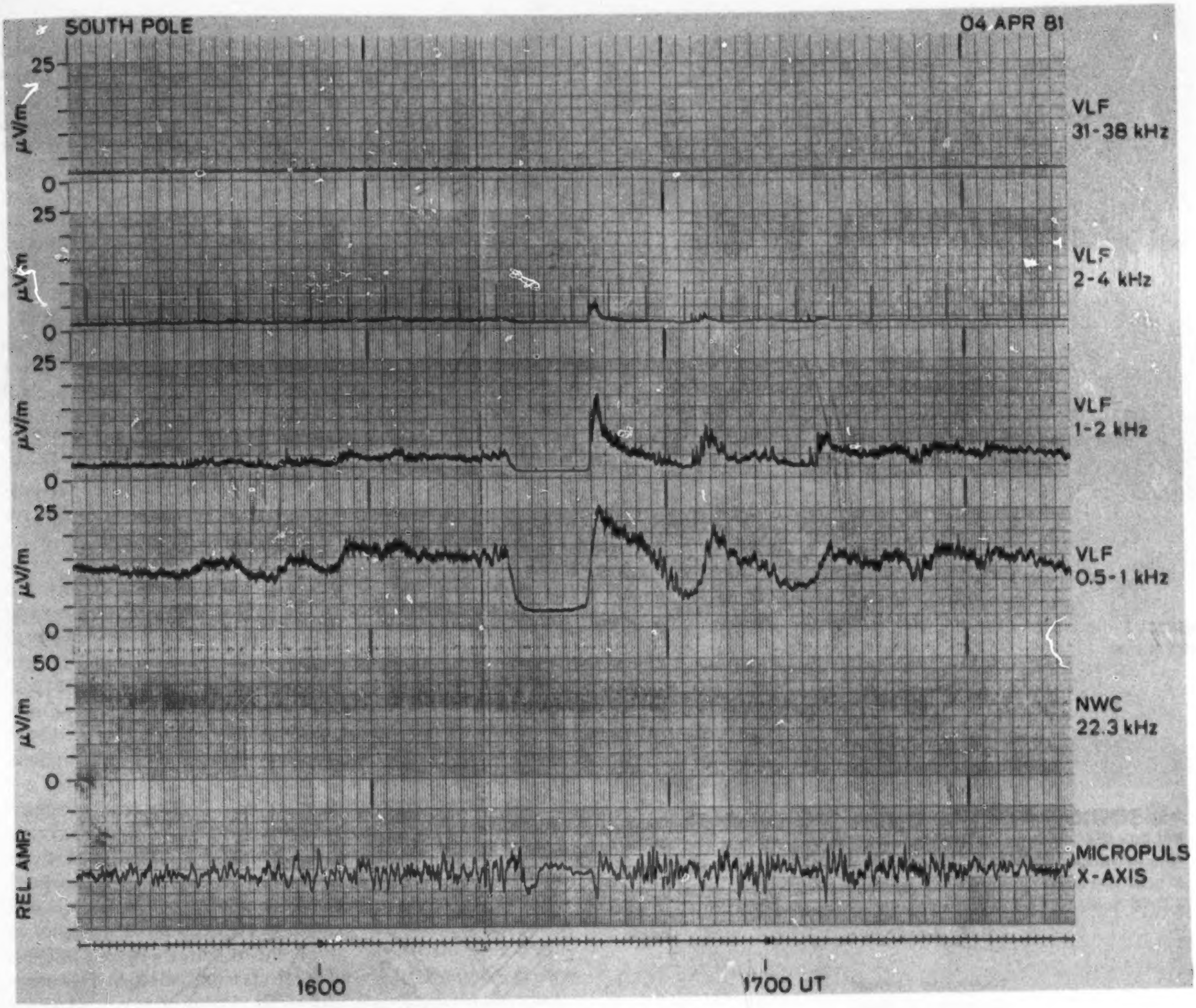

Figure 2. Chart record showing a lull in very-low-frequency (VLF) activity simultaneous with similar activity in micropulsations. REL.AMP. = relative amplitude; μV/m = microvolts per meter. (NWC indicates the signal from a transmitter in Australia and is irrelevant to this article.)

possible to analyze comparative travel times and determine possible source regions for this activity. Data such as these provide a good probe for analysis of field line structure and identification of interaction regions between waves and particles.

Figure 3 (page 228) shows a series of 6 days for which the low VLF channels indicate a distinctive lull in the midst of normal dayside activity. This feature was discovered during efforts to locate a signature of cusp passage in parallel with work being done with riometer data. No evidence has yet been found to link the lull with the cusp, but the temporal location (geomagnetic noon is 1530 universal time at South Pole) makes the association with transit through the auroral oval a significant possibility. Work is currently being done to match this signature with similar features in riometer and photometer data.

The ability to do correlative work is an essential requirement in the study of upper atmospheric phenomena at South Pole Station. The multiplicity of correlations seen in the 1981 data underlines the complex nature of the the physical phenomena being observed and emphasizes the importance of continued cooperation among the various researchers.

This work was supported by National Science Foundation grant DPP 79-23171.

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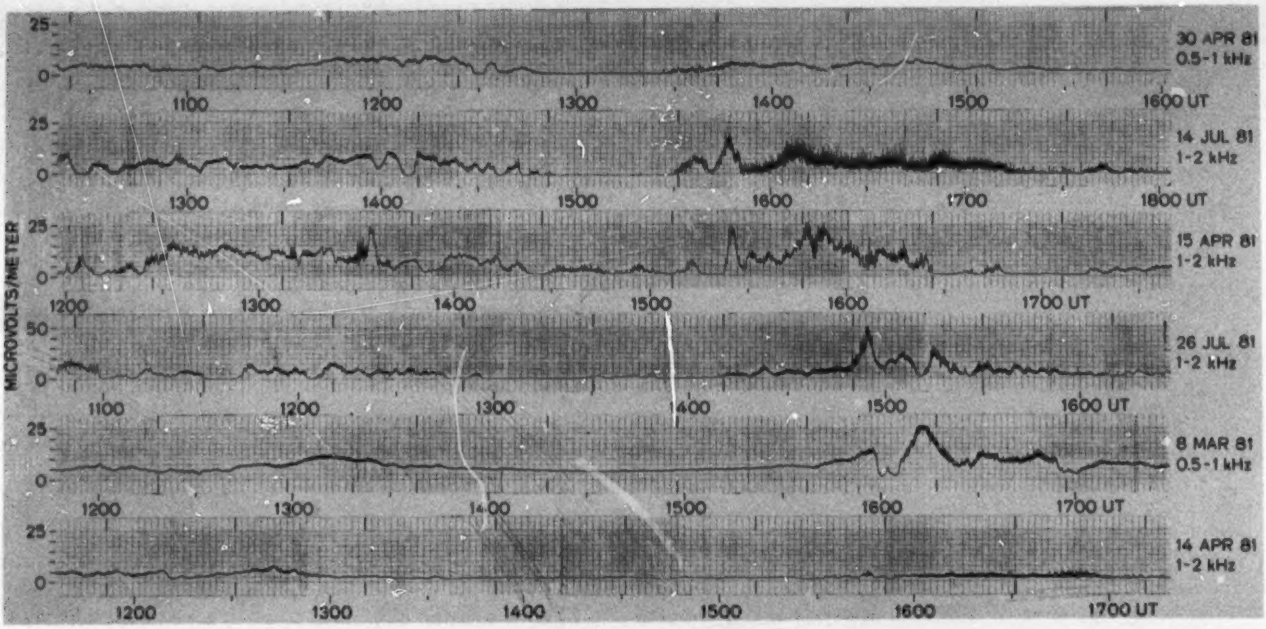

Figure 3. Six chart segments showing similar lulls in dayside very-low-frequency (VLF) activity that may correspond to spatial features in the auroral oval.

Geometry of the open region and South Pole Station

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Magnetospheric field lines are of two types. "Closed" field lines connect a pair of the geomagnetic conjugate points across the geomagnetic equator. "Open" field lines are interconnected with solar wind (or interplanetary) magnetic field lines across the magnetopause. Open field lines "originate" from a limited region in the polar region called the "open region." It is generally thought that the auroral oval approximately delineates the boundary of the open region.

It has long been thought that the open region has a simple quasi-circular geometry. This is indeed the case on the average, and, in particular, when the interplanetary magnetic field (IMF) has an appreciable southward component; in this instance the auroral oval has the well-known geometry. However, on the basis of a magnetospheric model, Akasofu, Covey, and Meng (1981) found that the geometry of the open region can vary considerably as the IMF changes its orientation, in particular when the IMF has an appreciable northward component. Fur-

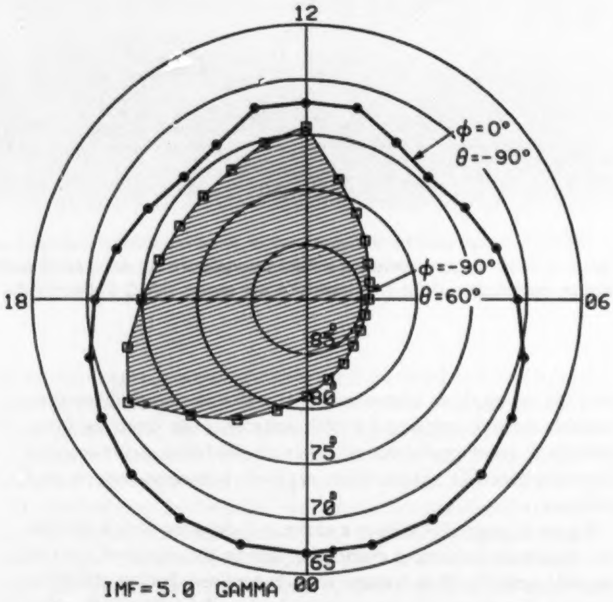

Figure 1. The geometry of the open region constructed on the basis of a magnetospheric model by superposing a uniform interplanetary magnetic field (IMF) of magnitide $B = 5\gamma$ and two sets of azimuth angles (ϕ) and latitude angles (θ): $\phi = 0°$, $\theta = -90°$ (dots), and $\phi = -90°$, $\theta = 60°$ (open squares).

ther, Meng (1981) has suggested recently that some of the so-called "polar cap arcs" that occupy the region enclosed by the average auroral oval are not really polar cap arcs. He has also suggested that during periods when the IMF has a northward component, the auroral oval widens toward higher latitudes and that some of the arcs appear in the widened oval. Lassen (1979) has suggested that in the northern polar region those arcs tend to appear in the evening sector when the IMF east-west (By) component has a positive value and in the morning sector when the By component has a negative value. Study of the magnetospheric model indicates that the situation is reversed in the southern polar region.

Figure 1 shows the geometry of the open region in the northern polar region for a uniform IMF magnitude $B = 5\gamma$, when (1) $\phi = 0°$, $\theta = -90°$, and (2) $\phi = -90°$, $\theta = 60°$, constructed on the basis of our magnetospheric model, where ϕ and θ denote the azimuth angle from the Sun-Earth line in the equatorial plane and the latitude angle, respectively. The first situation provides us with a typical geometry of the open region surrounded by the average oval. When the second set of values for the angles is substituted, however, the open region (shaded region in figure 1) becomes considerably asymmetric with respect to the noon-midnight meridian. In this situation, all field lines originating from the region outside the shaded area become closed. The open region in the southern polar region is the mirror image of the open region in the northern polar region. Therefore, when the IMF By component is negative, the open region is centered in the evening sector in the Northern Hemisphere and in the morning sector in the Southern Hemisphere. On the other hand, when the IMF By component is positive, the open region is centered in the morning sector in the Northern Hemisphere and in the evening sector in the southern hemisphere. This asymmetric open region can be seen in figure 2, which presents all-sky photographs taken from South Pole Station and DMSP (Defense Meteorological Satellie Program) photograph, all taken on 12 June 1975 when the IMF had a positive By component. The DMSP photograph (the large photograph at the upper left corner) was taken as the DMSP satellite passed nearest to the South Pole. It shows that the morning half of the "polar cap" was filled with a number of arcs which align approximately along the noon-midnight meridian, while the evening half of the "polar cap" was relatively free of arcs. The smaller all-sky photographs show how these arcs vary in time. A preliminary examination of other all-sky photographs from South Pole Station and corresponding DMSP photographs indicates that such arcs are absent when the By component is negative. If this conclusion is confirmed in further study, a study of auroral arcs at approximately 75° in invariant latitude may provide a clue in understanding the interaction between the solar wind magnetic field and the magnetosphere. The South Pole Station is ideally suited for this study.

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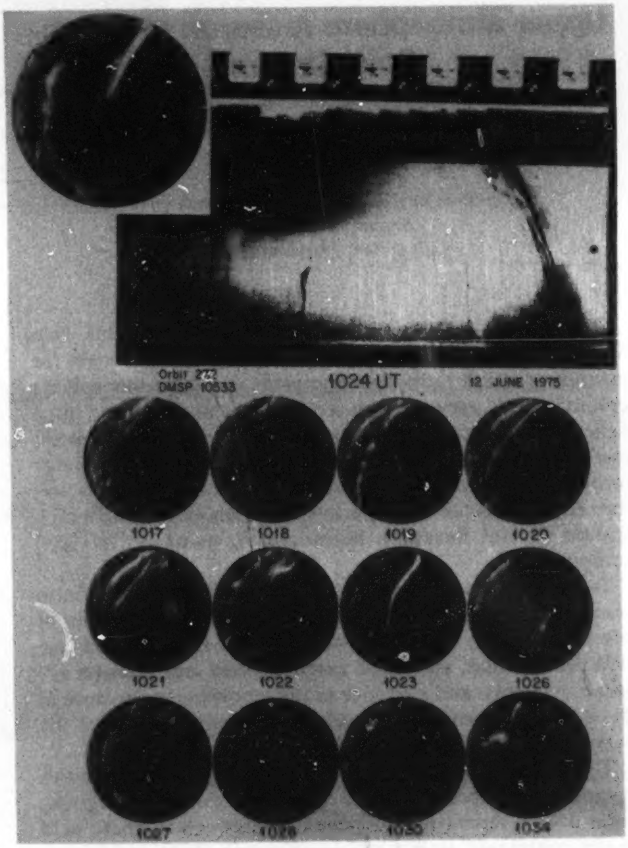

Figure 2. All-sky photographs taken from South Pole Station just before and just after 1024 universal time on 12 June 1975 and the corresponding Defense Meteorological Satellite Program photograph taken at 1024 universal time. The magnetic noon meridian is indicated by a line from the invariant South Pole marked by the cross.

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Upper atmosphere research at South Pole Station

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The facilities for upper atmosphere research at South Pole Station recently have been expanded to include instruments for measuring cosmic radio noise (riometer, or relative ionospheric opacity meter), very-low-frequency radio emissions, and magnetic field variations (fluxgate and search-coil magnetometers) (see table). Data from these instruments are simultaneously recorded on digital magnetic tape. Initial data reduction is performed at the station by the winter-over laboratory scientist, J. Dalton (Bartol Research Foundation), using an HP-1000 computer.

Two weeks of recorded data were returned before the winter season began. With even this limited data, a wide variety of phenomena were observed, including solar-flare-induced particle precipitation, correlated magnetic field and riometer absorption events, and evidence of the ionospheric signature of the magnetospheric cusp. Study of the characteristics of the cusp region is a principal emphasis of the new facilities.

The magnetospheric cusp is a dayside region of the Earth's magnetic field formed by the solar-wind-distorted magnetic polar field; it represents the boundary between magnetic field shells containing untrapped plasma and those containing trapped or quasi-trapped particles. The northern and southern polar cusps map onto circular areas of the atmosphere, within which untrapped plasma is precipitated into the ionosphere directly from the boundary layer (magnetosheath) between the Earth's magnetic field and the interplanetary magnetic field. South Pole Station passes within the southern magnetospheric cusp, and thus is an ideal observatory for the study of cusp-related atmospheric effects.

Studies of auroral activity in the polar region have revealed a marked decrease in auroral displays in the midday sector (Akasofu 1976; Snyder and Akasofu 1976). This "midday gap" in discrete auroral arc activity is a permanent feature of the dayside auroral oval; it is centered about the 1130 magnetic local time meridian and is about 2–3 hours wide (Dandekar 1979; Dandekar and Pike 1978). It has been proposed that this feature is the ionospheric projection of the polar cusp (Meng 1981).

Type of data/instruments included in the digital data acquisition system at South Pole Station and principal investigators

Instrument/Experiment	Institution/Principal investigator
Cosmic radio noise/ Riometer	University of Maryland/T. J. Rosenberg
VLF radio emissions	Stanford University/R. A. Helliwell
Magnetic field variations	
Fluxgate magnetometer	Bell Laboratories/L. J. Lanzerotti
Search-coil magnetometer (micropulse)	University of New Hampshire/R. L. Arnoldy, and University of Minnesota/ L. S. Cahill, Jr.

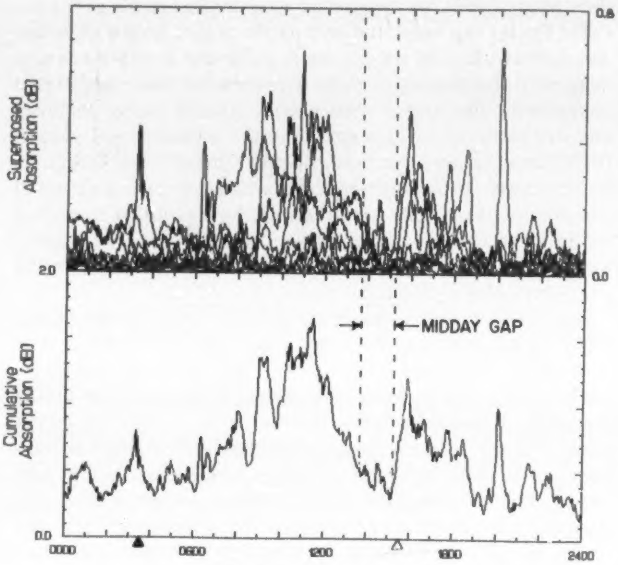

Figure 1. Midday gap in riometer absorption. The open triangle at 1530 universal time (UT) identifies local magnetic noon, and the solid triangle at 0330 UT identifies magnetic midnight. dB = decibels.

Early analysis of 30 megahertz riometer data from South Pole Station has revealed a decrease in the absorption of cosmic radio noise strikingly similar to the decrease in auroral displays in the midday sector and coincident with it (figure 1). With few exceptions, the larger absorption events coincide with South Pole Station's being within the region of discrete auroral arc activity (approximately 0900–2100 universal time). The midday gap represents a significant decrease in absorption between broad morning and afternoon peaks. Riometer absorption is a sensitive indicator of electron precipitation (energy > 10 kiloelectronvolts; flux > 0.0001 erg per square centimeter-second-steradian), and the finding of a decrease in absorption of cosmic radio noise suggests that the precipitated fluxes of hard electrons from the magnetosheath are much smaller than those from the trapping regions of the magnetosphere.

An example of an event that occurs frequently when the station is within the region of discrete auroral activity is shown in figure 2. A strong riometer absorption event (1.8 decibels at 30 megahertz) at 2000 universal time correlates well with the data from the fluxgate magnetometer and coincides with the start of oscillations in the micropulsation detector and an abrupt cutoff of very-low-frequency (VLF) emissions. This event demonstrates the attenuation of propagated VLF emissions and cosmic radio noise by precipitating electrons; in addition, associated changes in ionospheric electrical conductivity may be related to the magnetic field perturbations.

The digital data acquisition system at South Pole Station was installed in late December 1981 by L. F. Lutz, D. L. Detrick, and T. J. Rosenberg. A similar installation at McMurdo Station (Detrick and Lutz 1981) will be operated during the 1982 winter season by B. McKibben (University of Alaska).

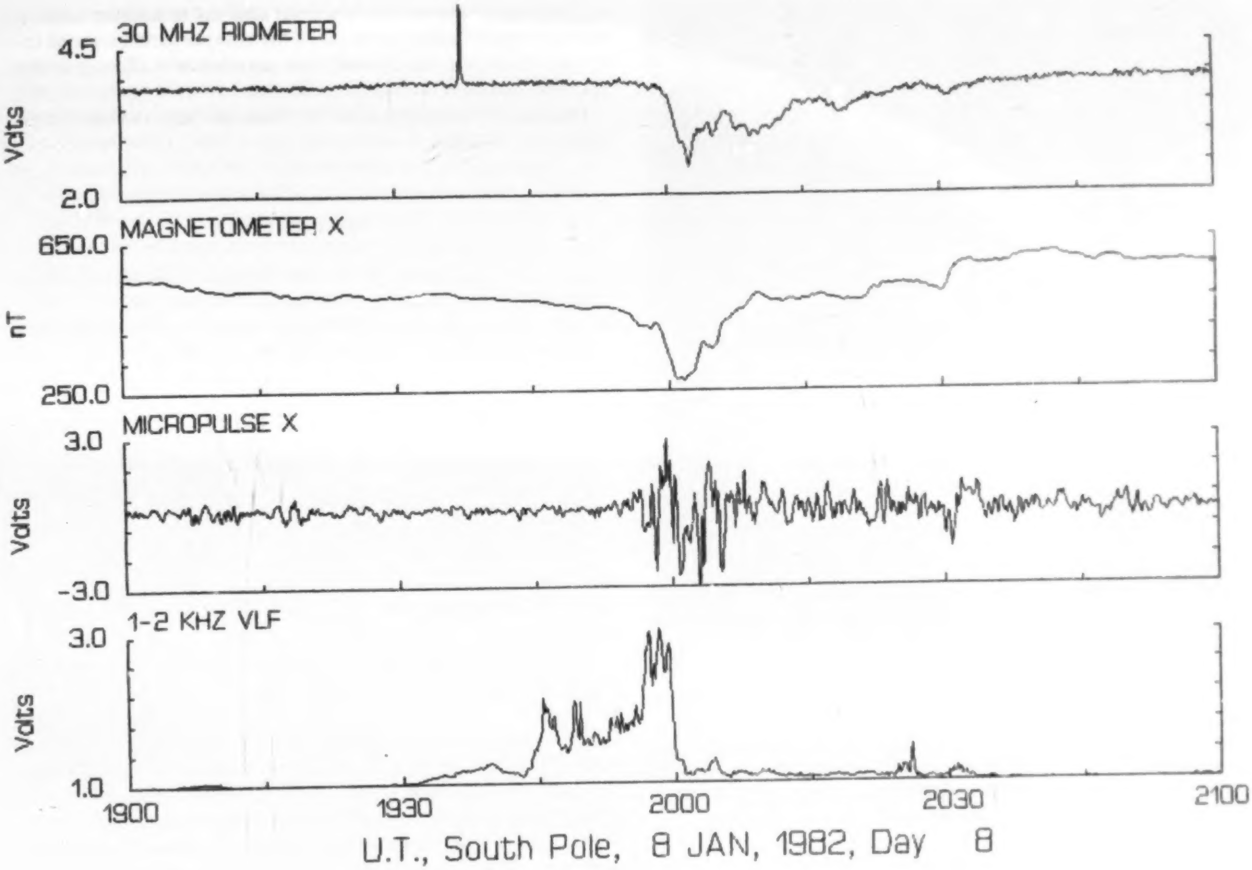

Figure 2. Correlated riometer-VLF-magnetometer event, South Pole Station. nT = nanotesla.

This work was supported by National Science Foundation grant DPP 79-25074.

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Dayside aurora studies with a color keogram camera

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The single-channel (black and white) and dual-channel (color) keogram cameras operated at South Pole Station during the 1980 and 1981 austral winters have been described previously (Eather and Mende 1980, 1981). Data obtained with the single-channel camera reveal extended periods of poleward and equatorward drifting auroral structures (see Eather and Mende 1980). My colleague and I recently obtained simultaneous interplanetary field data and are trying to understand these motions in terms of changing convection patterns.

The color camera operated in 1981 worked well and provided color-coded keograms, where the color relates to the energy of the precipitating electrons (0.1–10 kiloelectronvolt energy range). The keograms show that cusp precipitation is almost always characterized by electron energies of order of 100 electronvolts, even during strong magnetic activity. However, more energetic precipitation superimposes sporadically, and we plan to investigate the conditions under which these events occur. Examples of these data are not shown here because color plates cannot be printed in this publication.

The color camera will continue to operate through the 1982 austral winter and will provide essential data on the cusp aurora for coordinated experiments planned with other investigators who have recently installed equipment in the new Cusp Laboratory at South Pole Station. The new instruments include riometers, magnetometers, an ionosonde, very-low-frequency and micropulsations equipment, and an image-intensified monochromatic all-sky camera. This comprehensive set of instruments should lead to valuable correlative studies over the next few years.

This research was supported by National Science Foundation grant DPP 78-23513.

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Large-scale motions and structure of the Sun

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The unique advantages of conducting certain types of solar observations at the geographic South Pole have become widely recognized. During the 1981–82 austral summer, two projects were successfully completed.

First, development of the tower telescope facility (Pomerantz, Wyller, and Kusoffsky 1981) in preparation for studies of the chromospheric network was brought to a satisfactory conclusion by the Bartol group. Modifications of the computer control system and of the optics following the focal plane were made on the basis of the experience gained during the initial testing period immediately following construction in 1980–81. Figure 1 is a photograph of a field 3.8 centimeters in diameter selected from the 20-centimeter solar image. The resolution of roughly 1.5 seconds of arc may well be limited by the primary glass optics, which have a long history of prior use at the Capri Solar Observatory of the Swedish Royal Academy of Sciences. It is noteworthy, however, that all the glass components, as well as the drive motors and gear trains, survived the 1981 winter *in situ* at the remote Polar Solar Observatory site. This proved that an early start immediately following station opening, in order to capitalize on the optimal atmospheric conditions that prevail then, is feasible, and this will be attempted in future years.

The objective of the second project, a collaborative undertaking of the Bartol Research Foundation, the Kitt Peak National Observatory, and the National Aeronautics and Space Administration, was to obtain spatially resolved observations of global solar oscillations to complement and extend the exceedingly successful earlier full-disc studies (Pomerantz, Grec, and Fossat 1980). The aim was to define the characteristics of the spectrum of solar acoustic modes that have periods of around 5 minutes, representing spherical harmonics of degree ranging from 0 to

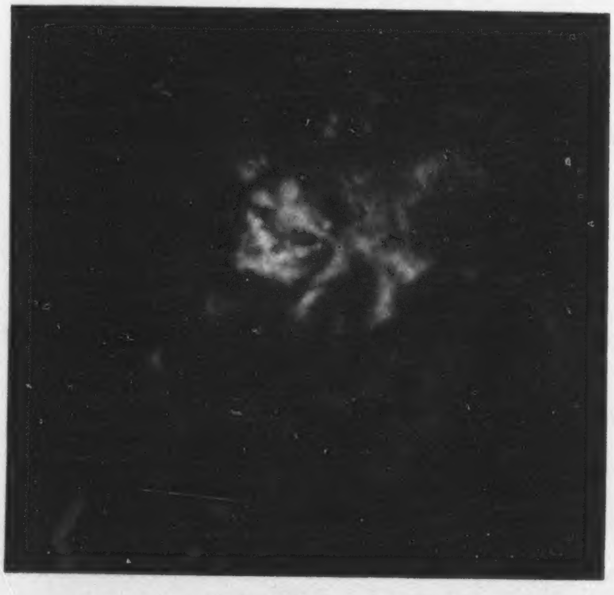

Figure 1. Photograph taken through a hydrogen-alpha filter (6,563 angstroms) with the 9-meter tower telescope at South Pole. The image represents roughly 1/28th of the Sun's total area.

100. These oscillations, which probe the depth variation of solar structure and rotation, are crucial for solar seismology but are exceedingly difficult to observe from low-latitude observatories.

The technique involved recording images of the Sun formed by the small telescope that was especially designed for and used in the earlier work with a high-precision digital camera. The images consisted of 244 by 192 picture elements; the intensity at each element was recorded with a precision of the order of 1 part per 10,000 every 90 seconds. A narrow-band optical filter isolated the solar atmosphere temperature minimum where the oscillations exhibited a maximum signal:noise ratio.

Poor weather following the rather late start of observing, upon completion of set up at the remote [illegible] (figure 2), was a limiting factor this year, and our hoped-for 5-day continuous run did not materialize. However, four sequences totaling, 6,681 images (figure 3) were recorded. The time-consuming, detailed data analysis is under way and has already confirmed previous observations of low-degree spherical harmonic oscillations of the Sun. Our observations show that the envelope of the amplitude distribution is shifted to higher frequencies than in the previous measurements. This effect is a consequence of the finite response time of the solar atmospheric temperature to velocity perturbations, and further study should provide new information about the thermodynamic properties of the temperature minimum region of the Sun. Analysis of oscillations with degree between 2 and 100 remains to be completed.

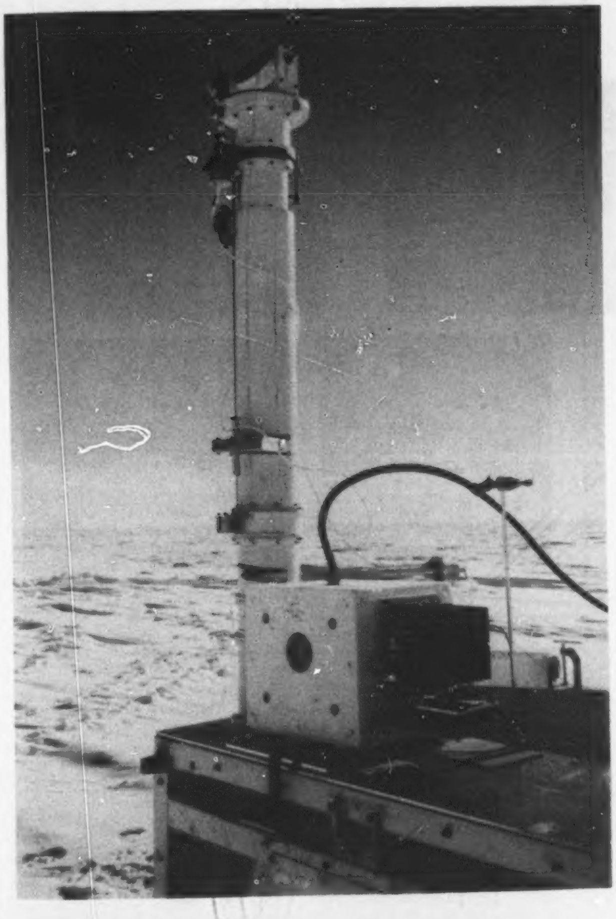

Figure 2. The apparatus used for spatially resolved observations of global solar oscillations. The moving flat mirror (heliostat) on top of the small telescope sends sunlight vertically down through a lens and other optics. The final image of the sun is formed on a two-dimensional, diode-array camera at the rear of the insulated experiment package. At the back of the camera, a fan blows air across black fins that are part of a cooler (despite the ambient temperature of −30°C!) used to increase the sensitivity of the diode array detector.

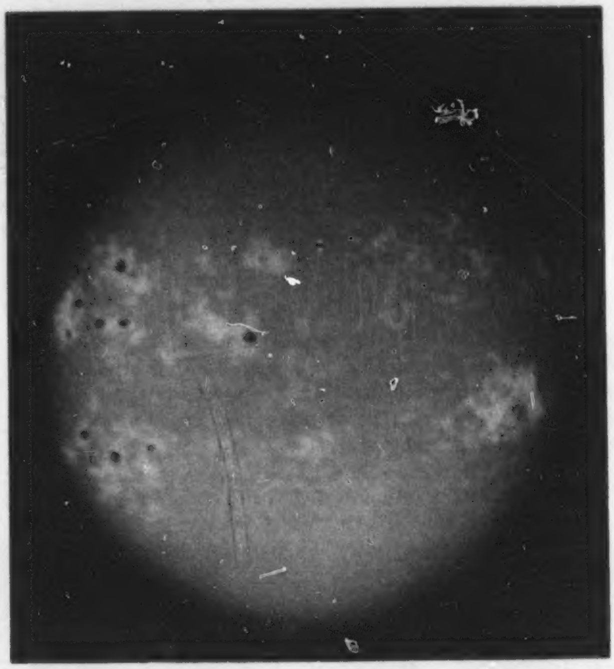

Figure 3. An image of the Sun recorded with the experiment package shown in figure 2. Each picture element is about 10 arc seconds on a side. The image was filtered to isolate a cool part of the upper solar atmosphere. This is one of approximately 6,600 images recorded on magnetic tape during our observations.

In addition to the authors, R. C. Pfeiffer, C. H. Tsao, John Dalton, and Dick Aikens participated in the fieldwork. This work is supported by National Science Foundation grant DPP 78-22267. Kitt Peak National Observatory is operated by AURA, Inc., for the National Science Foundation.

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Imaging of atmospheric emissions in Antarctica

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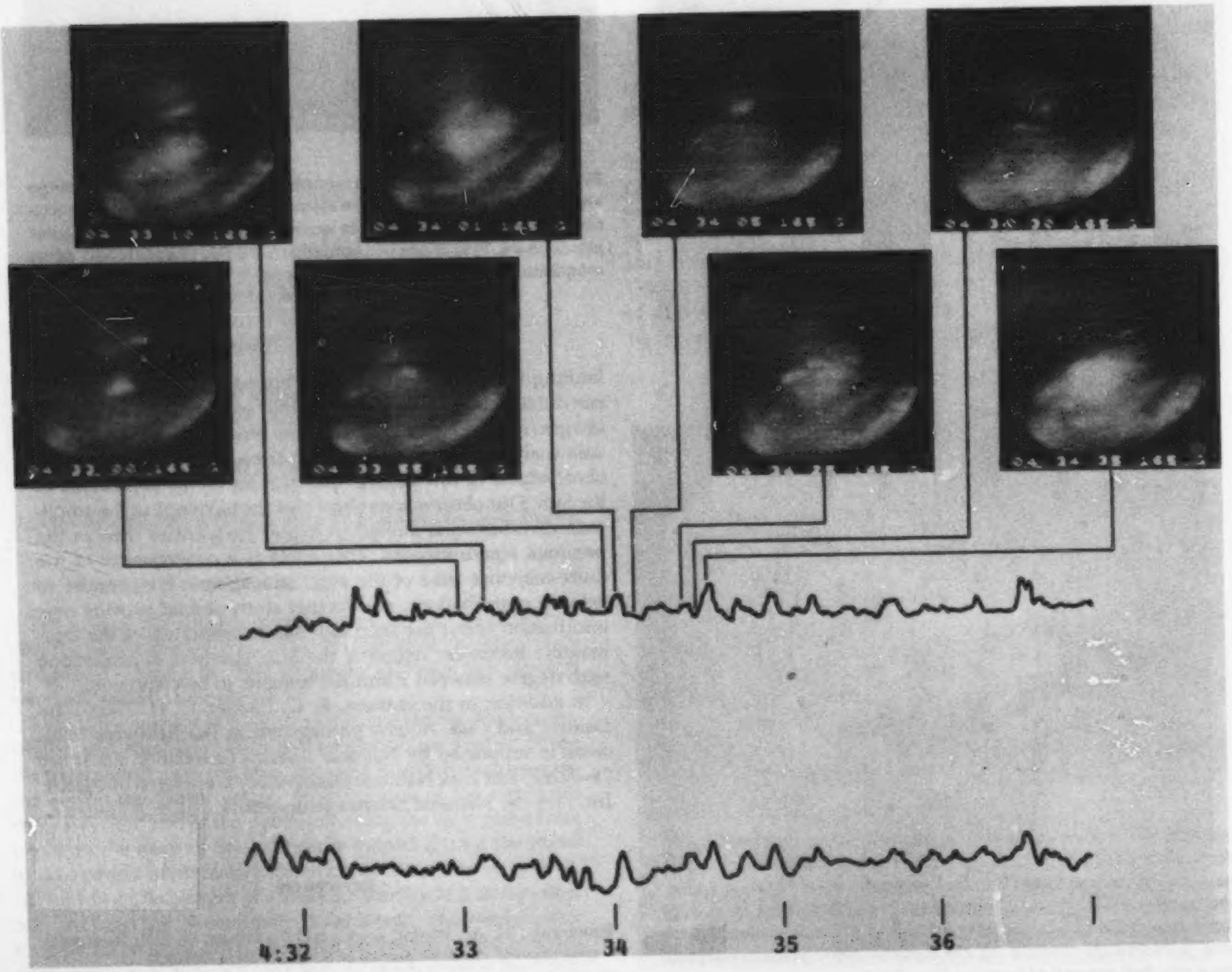
In a continuing program of investigating natural atmospheric emission phenomena on the antarctic continent, Lockheed Palo Alto Research Laboratory has collaborated with Boston College in the construction and fielding of a special-purpose optical imaging instrument for the detection and recording of optical emissions in the atmosphere.

In earlier phases of this program at Siple Station, we were successful in detecting particle-induced optical emissions that were coincident with wave activity in the very-low-frequency (VLF) and ultra-low-frequency (ULF) range. Initially, photometers were used in coordinated experiments with both VLF and ULF wave detectors. The observed correlations added to our understanding of wave particle interactions and led to the design and construction of the new special-purpose instrument for further studies. This instrument is a low-light-level television that has a fish-eye lens and images the whole sky. It is capable of detecting the faint particle-induced emission using a suitable selected spectral feature of the emission.

The new instrument provides a visual record of the spatial extent and the scale of the correlated optical features. The figure presents a sample data set of correlated ULF pulses as measured by the University of New Hampshire-University of Minnesota magnetometer. The optical pulses shown on the top trace dem-



Correlated optical and magnetic pulses at Siple Station. Top trace is the optical emission on the center of the sky as measured by the integration of the video signal. Also shown are the all-sky images from the television system at times appropriate to maximums and minimums in the pulsing. Bottom trace is the north-south component recorded by the University of New Hampshire-University of Minnesota magnetometer. Magnetic north (equatorward) is up.

onstrate very clear correlations. All-sky images for the various features also are shown in the figure.

The small-area optical pulsation at 0433 universal time (UT) leaves very little trace on the magnetometer. At 0433:10 UT a much wider area pulsation appears, one that produces noticeable positive excursion of the magnetometer trace. Perhaps the most distinct magnetometer pulse occurs shortly after 0434 UT. The television shows directly the shape and size of the optical pulse causing the magnetometer excursion. A similar event occurred at 0434:35 UT. Most of the properties of these types of magnetometer and optical correlations have been explained in terms of ionospheric currents (Arnoldy et al. in preparation) and or field-aligned currents (Engebretson et al. in preparation). These television images will be able to clarify the relative importance of ionospheric currents in the generation of magnetic signatures.

In early studies at South Pole Station, scanning photometers were used to monitor the dayside cusp auroral precipitation. The position of the dayside cusp is an important parameter for the understanding of magnetospheric dynamics; for the continuous monitoring of the cusp a new low-maintenance instrument, the image-intensified slit camera, was developed (Eather and Mende 1981).

For the 1982 austral winter a new instrument has been added at South Pole Station, the image-intensified, all-sky film camera. The addition of this instrument became necessary because work with the meridian slit camera identified new features in the cusp precipitation. These are meridianally moving structures probably associated with Sun-aligned arcs. To see these structures, we needed highly sensitive, two-dimensional image data. Since conventional all-sky cameras are not sensitive enough to pick up 90 percent of the low-level cusp activity, we constructed a special monochromatic (6,300-angstrom), image-intensified all-sky camera for this purpose. The camera was installed at South Pole Station for data collection during the austral winter of 1982.

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Magnetic field and particle precipitation observations at the South Pole

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As a part of a new program to study the Southern Hemisphere magnetospheric cusp region at Amundsen-Scott South Pole Station, magnetic field and riometer measurements are being made in association with a variety of other upper atmosphere geophysical investigations. The purpose of these studies is to learn more about the physical processes that operate in the magnetospheric cusp region, particularly as related to the entry of interplanetary plasma into the magnetosphere and its penetration to the ionosphere and upper atmosphere. It has been suggested (e.g., Bolshakova, Troitskaya, and Hessler 1975; Rostoker, Samson, and Higuchi 1972) that a wide range of

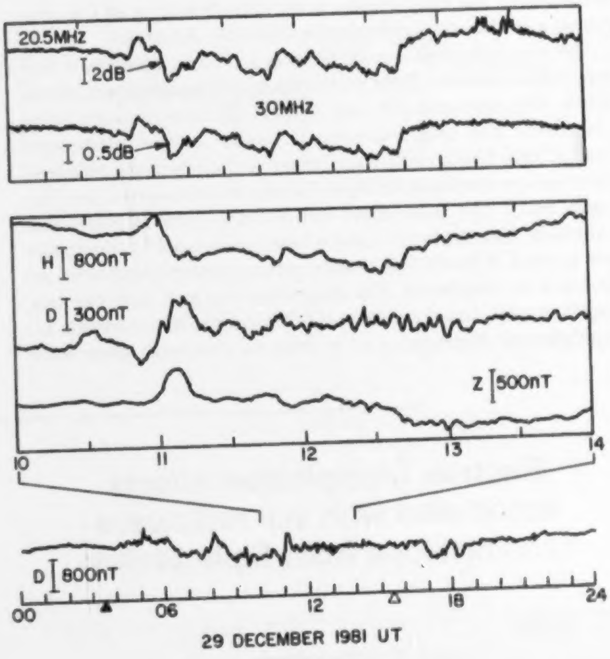

Figure 1. Magnetic field and riometer data from the South Pole Station on 29 December 1981. MHz = megahertz; dB = decibels; nT = nanotesla; UT = universal time; H = north-south; D = east-west; Z = vertical.

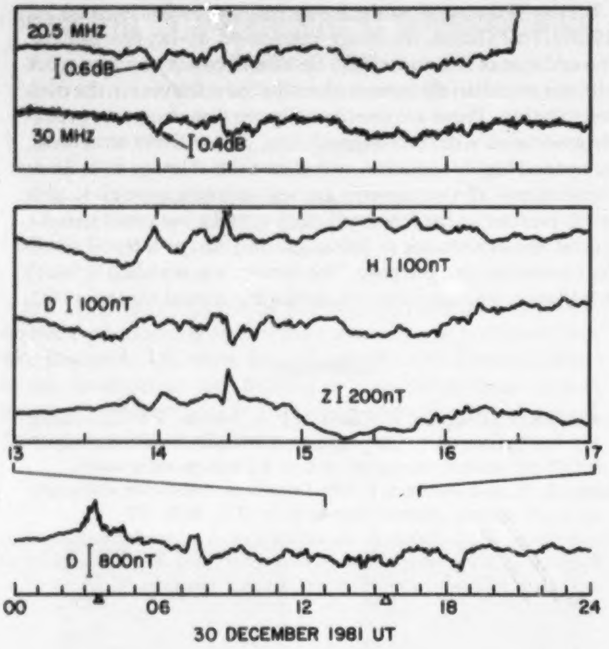

Figure 2. Magnetic field and riometer data from the South Pole Station on 30 December 1981. See figure 1 for explanation of abbreviations.

hydromagnetic waves can be present in the cusp region. The objective of this detailed study of magnetic field and riometer variations in the cusp region is an understanding of the phenomena in the context of magnetospheric dynamics.

The magnetic field measurements are being taken by a fluxgate magnetometer; field variations in the geomagnetic north-south (H), east-west (D), and vertical (Z) directions are being measured. The magnetometer is similar to the instruments used at Siple Station and at a number of stations in the Northern Hemisphere conjugate to Siple (Lanzerotti, Hasegawa, and Tartaglia 1972). The instrument has a noise level of about 0.25 nanotesla. Cosmic radio noise is being measured by two riometers located at South Pole Station whose center frequencies are 20.5 and 30 megahertz. The magnetometer and riometer data, together with data from several other geophysical sensors, are multiplexed, digitized, and written in computer-compatible format on magnetic tape. Both the riometer and magnetometer voltage outputs are sampled at 1-second intervals.

The data plotted in figures 1 (page 235) and 2 are for 2 of the 14 days of data obtained during the 1981–82 austral summer. These data are selected to illustrate both the large fluctuations in the magnetic field that can be observed during local daytime and the association of the magnetic field and riometer measurements.

At the bottom of each figure is plotted the D-component magnetic field data for 24 hours during 29 and 30 December 1981. The solid and open triangles indicate local magnetic midnight and local magnetic noon, respectively, at the South Pole. Higher resolution data for all three magnetic field components and the two riometer frequencies are shown for a selected interval on each of the days. These latter data illustrate in more detail the fluctuations in the magnetic field and the association between ionosphere fluctuations (reflecting particle precipitation) as measured by the riometer and magnetometer fluctuations. The data of 29 December show rather good association between fluctuations in the cosmic noise absorption and the magnetic field variations; the correspondence is not as good during the interval plotted for 30 December.

Future work with these data will involve examination of higher time resolution variations in the magnetic field to study hydromagnetic waves in the cusp and their relationship to particle precipitation. It can reasonably be expected that these data, together with their study in conjunction with other geophysical measurements in progress at the South Pole, will provide considerable new insights into the physical processes in the magnetospheric cusp.

The logistics support for the Bell Laboratories measurements is provided by the Division of Polar Programs of the National Science Foundation (NSF). The work at the University of Maryland is supported by NSF grant DPP 79-25014.

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Electron precipitation effects associated with VLF radiowave transmissions from Siple Station

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From the inception of Stanford University's very-low-frequency (VLF) wave injection experiments at Siple Station in 1973, evidence of controlled precipitation of energetic electrons into the upper atmosphere has been sought with a variety of techniques. Although wave growth and suppression effects, as well as discrete emission triggering, have provided ample evidence that wave-wave and wave-particle interactions are induced in the magnetosphere by the Siple VLF transmitter, definitive evidence of related particle precipitation effects has not been found in previous work. In this article, two examples of X-ray, riometer, and magnetometer variations are presented as evidence of the influence of Siple VLF transmissions on particle precipitation.

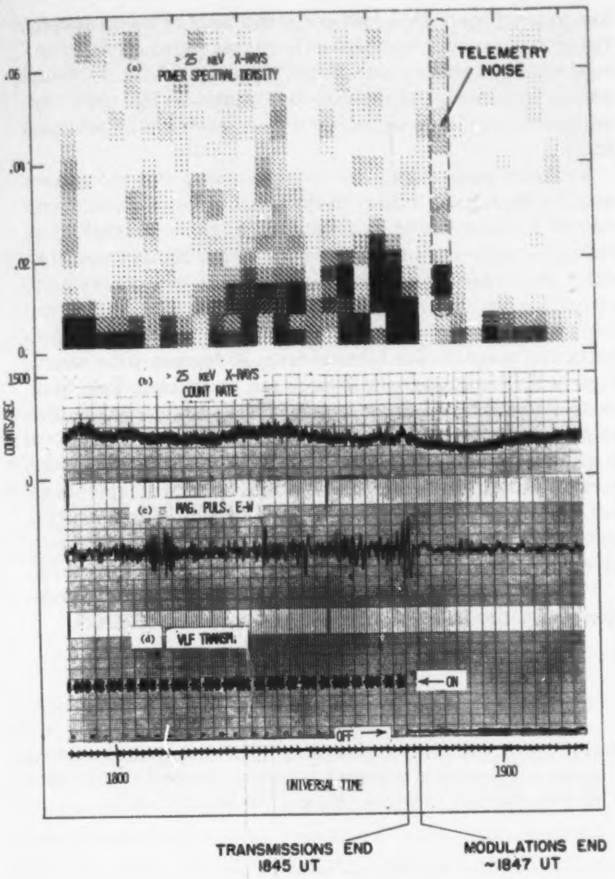

Figure 1. X-ray (a, b) and magnetic pulsation (c) data recorded during a long sequence of very-low-frequency (VLF) transmissions (d), Siple Station, 5 January 1981. kev = kiloelectronvolt; E-W = East-West.

Figure 1(b) illustrates the counting rate of bremsstrahlung X-rays having energies greater than 25 kiloelectronvolts recorded during balloon observations over Siple on 5 January 1981 by the University of Maryland. Long-period (approximately 2-minutes) fluctuations of the counting rate are evident from approximately 1820 to approximately 1847 universal time. The power spectral density of the counting rate variations, given in figure 1(a), confirms the significant reduction of modulation amplitude at approximately 1847 universal time, within 2 minutes of the termination, at 1845 universal time, of a long series of VLF transmissions [figure 1(d)].

The precise format of the transmission sequence, which consisted of rising-, falling-, and constant-frequency tones in the frequency range 4.5–5.5 kilohertz, need not be considered in detail here. The important point is that, following the abrupt termination of the transmissions, the long-period modulation of the electron precipitation (i.e., X-rays) ceased and the counting rate decreased steadily to nearly the background level at approximately 1855 universal time before a new increase began. Magnetic pulsation activity of similar period in the east-west component [figure 1(c)], recorded by the University of New

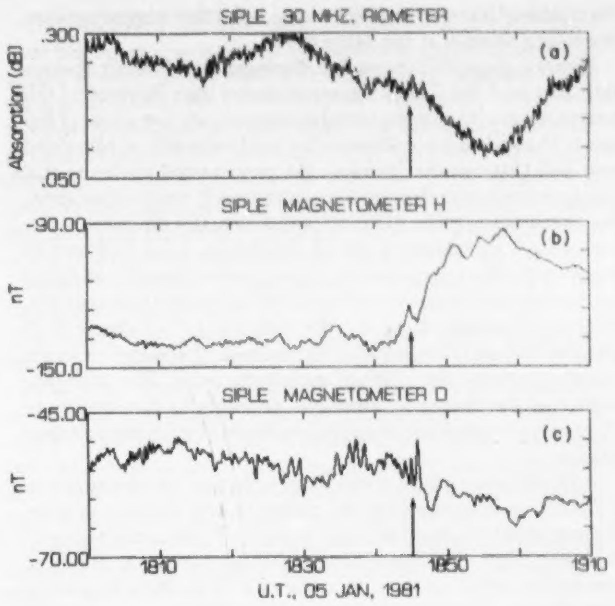

Figure 2. Riometer (a) and fluxgate magnetometer (b, c) data for the time period covered by figure 1. Very-low-frequency transmissions terminated at the time indicated by the arrow. dB = decibel; nT = nanotesla; MHz = megahertz.

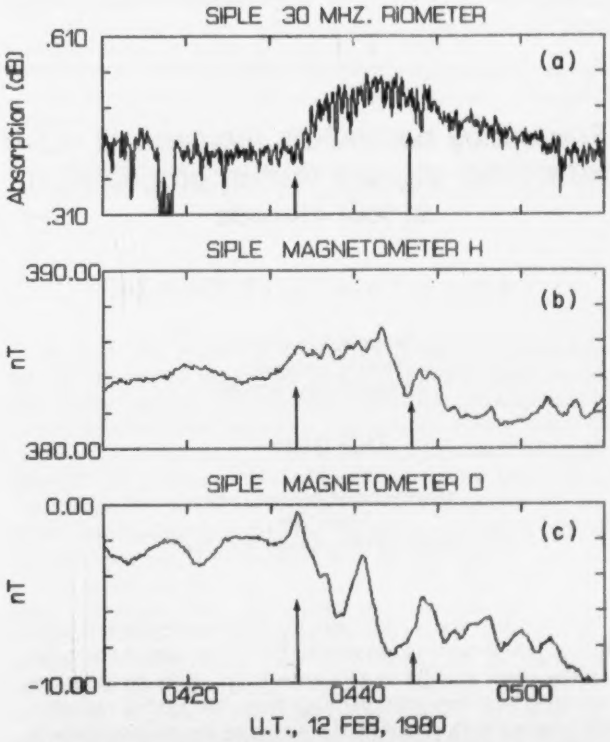

Figure 3. Riometer (a) and fluxgate magnetometer (b, c) data for another event associated with the Siple transmitter. The onset and the termination of the transmission sequence are indicated by the arrows. See figure 2 for explanation of abbreviations.

Hampshire/University of Minnesota induction magnetometer, decreased sharply at the same time.

Figure 2 (page 237) shows the 30-megahertz riometer absorption data and the fluxgate magnetometer data [horizontal (H) and east-west (D) components] accompanying the event of figure 1. These data were obtained by the University of Maryland and Bell Laboratories. Because the precipitated electrons that produce the X-rays also produce enhanced D-region ionization, the absorption profile of figure 2(a) is virtually the same as the profile of X-ray counting rate in figure 1(b). As is indicated in figure 2(c), when transmissions cease (arrow) there is an almost immediate reduction of rapid modulations in the D component. Within 10 minutes there is a 50-nanotesla (nT) increase in H [figure 2(b)] and 0.1-decibel (dB) decrease of absorption to the nearly quiet-day level before increasing again. The changing nature of the magnetic variations probably is due mainly to changes of ionospheric conductivity caused by the precipitation effects.

A second example of transmitter influence on electron precipitation is illustrated by the riometer and fluxgate magnetometer data presented in figure 3 (page 237; data collected on 12 February 1980). This figure depicts the case where the principal absorption effect (a) is an increase of 0.13 decibels beginning with the onset of transmissions, followed by a recovery to the preexisting level beginning with the termination of transmissions. The recovery is essentially complete after a time approximately equal to the duration of the transmission sequence, which had the same format as that used in the event of figure 1.

In this event the absorption profile (ignoring noise spikes) is rather smooth, even though there is a significant enhancement of long-period magnetic pulsation activity, principally in the D component [figure 3(c)], initiated at the onset of transmissions. The global magnetic disturbance level was extremely quiet (auroral electrojet indices of less than 30 nanotesla) for ± 3 hours around this time. Thus, it seems highly unlikely that the riometer response could have been related to even minor substorm activity.

As shown here and in other events studied, it is not uncommon for there to be a delay in the onset of ionospheric effects relative to the onset of transmissions and/or a persistence of effects for some minutes beyond the termination of transmissions. As a possible interpretation, we note that the Siple VLF signal in space is not confined to magnetic flux tubes that extend into the magnetosphere from the immediate vicinity of Siple. In particular, magnetic flux tubes as far as 30 degrees to the west of Siple at the same magnetic latitude can be affected (Bell, Inan, and Helliwell 1981). As a consequence of the eastward azimuthal drift of trapped electrons in the geomagnetic field, the effect of transmitter-induced perturbations of the electron population on flux tubes to the west of Siple would be seen at Siple somewhat later. Calculations of the expected location of wave-particle interaction regions, based on observed time delays and reasonable estimates of electron energy, appear to support this model.

This work was supported in part by National Science Foundation grants DPP 80-12901, DPP 79-25014, and ATM 80-02423.

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Frequency bandwidth increase of VLF transmitter signals during propagation at low altitude

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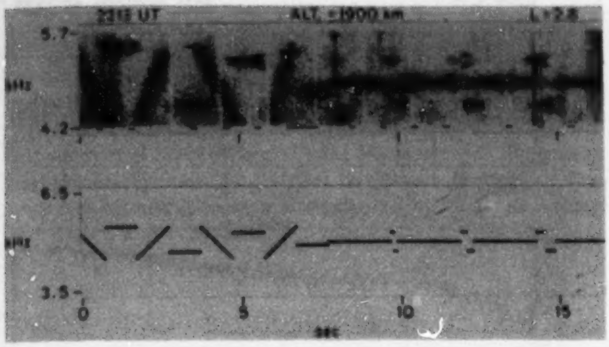
Very-low-frequency (VLF) wave-injection experiments involving the Siple Station VLF transmitter have been carried out in the past few years in order to gain knowledge of the mechanisms through which energetic particles from the Earth's radiation belts interact with coherent VLF waves in the magnetosphere (Bell, Inan, and Helliwell 1981; Helliwell and Katsufrakis 1974). This knowledge is essential if we are to understand the processes that govern the lifetime of energetic particles in the Earth's radiation environment.

Although most of the scientific data concerning the wave-injection experiments has been acquired at ground stations (notably, at Roberval Station, Canada, which is magnetically conjugate to Siple Station), *in situ* satellite measurements have been very important in determining the properties of both the injected VLF waves and the interacting particles in the regions where the interactions take place (Bell and Inan 1981). In the past, data acquired on both high- and low-altitude satellites have indicated that most important VLF wave-particle interactions were taking place at high altitudes close to the magnetic equatorial plane. However, recent low-altitude VLF wave-injection experiments involving the Siple Station VLF transmitter, the Omega navigational transmitter in North Dakota, and the three satellites ISIS-I, ISIS-II (Canadian), and ISEE-1 (United States) have demonstrated the existence of a new phenomenon: initially narrowband (approximately 1 hertz) signals from ground-based VLF transmitters undergo a significant frequency bandwidth increase as they propagate through regions where energetic electron precipitation is thought to take place. The effect has been observed at satellite altitudes in the range 700–3,000 kilometers, and both upgoing and downgoing signals can show the effect. The affected transmitter signals lie in the range 4–20 kilohertz, and the frequency bandwidth increase can reach a value as high as 10 percent of the nominal frequency of the input signal. The bandwidth increase occurs only in the presence of impulsive VLF hiss and/or a lower-hybrid-resonance (LHR) noise band (Laaspere, Johnson, and Semprebon 1971) with an irregular lower cutoff frequency, and only for signals whose frequen-



Example of the frequency-bandwidth increase effect as observed in Siple Station transmitter signals. The data were acquired on the ISEE-1 satellite on 8 February 1982. The upper panel shows a spectrogram of the received signals, and the lower panel shows the format of the signals as actually transmitted. The received pulses have a bandwidth in the range 100–200 hertz, approximately two orders of magnitude larger than their bandwidth at transmission.

cy lies above the local LHR frequency at the satellite location. Dispersion in the components of the affected pulses suggests that the bandwidth increases may result from a Doppler shift effect in which the initial signal scatters due to plasma density irregularities at low altitude and couples into quasi-electrostatic modes of short wavelength. The large Doppler shift associated with these short-wavelength modes produces a significant increase in the bandwidth of the signal as observed on a moving satellite. Since impulsive VLF hiss and irregular LHR noise bands have been linked to energetic (energy < 1 kiloelectronvolts) electron precipitation, it appears likely that the irregularities that scatter the injected signals are produced by the precipitating electrons.

The bandwidth increase effect was observed first in signals from the Omega navigational transmitter as these signals propagated upward to the ISEE-1 and ISIS-I and -II satellites at low altitude in the Northern Hemisphere. However, recent ISEE satellite observations of Siple Station transmitter signals in the Northern Hemisphere have shown that the effect can occur in downgoing signals as well. An example of this behavior is shown in the figure, where the upper panel shows the downgoing, increased bandwidth signals from the Siple Station transmitter and the bottom panel shows the format of the signals as actually transmitted. In this example, the bandwidth of the transmitter pulses ranges from 100 to 200 hertz, which is approximately two orders of magnitude larger than the nominal bandwidth (approximately 1 hertz) of these pulses.

A new set of experiments is under way in which transmissions from Siple Station to the ISIS satellites are made while the satellites are in the Southern Hemisphere close to the zenith over Siple Station. One main purpose of these experiments is to study in detail the dependence of the bandwidth increase effect on the amplitude and frequency of the injected waves.

This research was sponsored by the National Aeronautics and Space Administration under grants NAS5-25744 and NGL-05-020-008.

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In situ measurements of Siple VLF transmissions entering the ionosphere

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During the 1980–81 antarctic summer, a sounding rocket campaign was conducted at Siple Station for the purpose of making *in situ* measurements of ionospheric plasma above the very-low-frequency (VLF) transmitter. VLF transmissions from Siple are known to be amplified in the magnetosphere under some geophysical conditions (Helliwell and Katsufrakis 1974). One goal of the sounding rocket campaign was to measure the power radiated from the Siple transmitter and injected into the ionosphere. This number is important as a boundary condition for theories of VLF wave amplification (Helliwell and Crystal 1973; Sudan and Ott 1971). All three Nike-Tomahawk sounding rockets were launched successfully from Siple under a variety of geophysical conditions. During the upleg of the last flight (flight 18.205, 10 January 1981), the Siple transmitter broadcast a continuous tone as the rocket entered the ionosphere. We describe here measurements of the continuous tone as it passed through the neutral atmosphere into the ionosphere.

Within the neutral atmosphere, the transmitted Siple VLF signal propagates as a plane-polarized, vacuum-mode wave. However, within the ionosphere it propagates as a right-hand-polarized, whistler-mode wave. In the latter case, the dielectric constant is asymmetric and frequency-dependent; for large-amplitude signals it can also be nonlinear. To enter the ionosphere, the Siple transmission must pass from the vacuum mode to the whistler mode. During the transition the signal is severely attenuated.

The 18.205 rocket trajectory during the upleg is shown in figure 1. Nose cone tip ejection occurred at 65 kilometers alti-

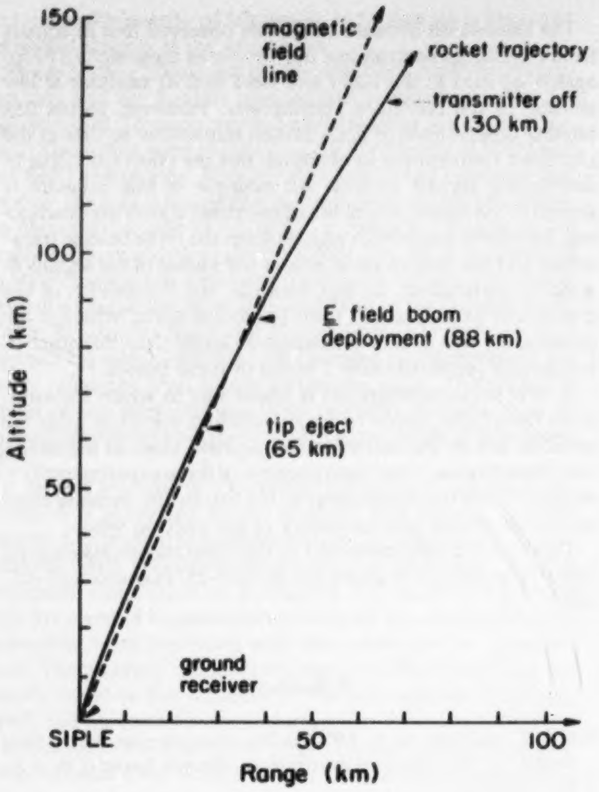

Figure 1. Sounding rocket trajectory during upleg, with major events indicated.

tude; above this altitude, high-quality wave measurements of the Siple transmission were obtained. VLF transmission continued until the rocket reached 130 kilometers altitude and had passed through the D and E regions (approximately 70–90 and 90–110 kilometers altitude, respectively). Hence, the rocket observed the Siple signal as it entered the ionosphere.

Within the neutral atmosphere, wave polarization was linear. The VLF magnetic field measurement was made with loop antennas attached to the rocket. Each loop responded to only one component of the wave vector magnetic field. Since the rocket was spinning at approximately 3 hertz, a linear-polarized signal measured by a spinning loop magnetometer should exhibit a 6-hertz amplitude modulation, while a circularly polarized signal should exhibit no amplitude modulation. The VLF magnetic field power from the Siple transmitter as measured on one of the 18.205 loop antennas is shown in figure 2. At low altitudes (75 kilometers) the Siple transmissions exhibited amplitude modulation at the rocket spin frequency and therefore were linear-polarized and were propagating in the vacuum mode. As the rocket's altitude increased, the signal exhibited less spin modulation and the peak amplitude decreased, due to an increase in electron density and electron-neutral collisions at higher altitudes. The magnetic field amplitude reached a minimum at 84 kilometers and then increased, while the spin modulation completely vanished at 90 kilometers altitude. The disappearance of the spin modulation suggests that the signal entered the whistler mode. The magnetic field amplitude increase was caused by an increase in the index of refraction ($n = cB/E$) to approximately 40. Although the magnetic field increased, the electric field decreased, resulting in an overall decrease in the Poynting vector.

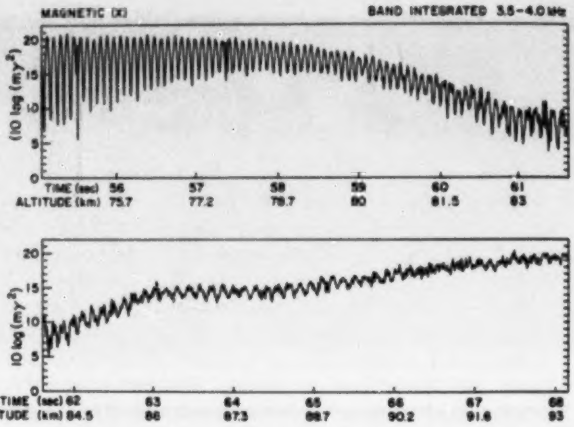

Figure 2. Very-low-frequency magnetic field power measured on the sounding rocket (upleg, flight 18.205, 10 January 1981). The amplitude modulation at low altitudes was produced by the rocket's spin.

The Poynting vector was determined by simultaneous measurements of both VLF electric and magnetic field on the rocket. The Poynting vector is given by $S = \frac{1}{2}\langle Re(ExH)\rangle$. Figure 3 shows Poynting vector measurements on the rocket as a function of range from Siple. The altitudes at which the measurements were taken are given in parentheses. The total power transmitted from Siple into the ionosphere can be determined by integrating the Poynting vector over the area into which Siple radiates. Using the results shown in figure 3, this suggests that when the Siple transmitter was operating at 50 kilowatts, the

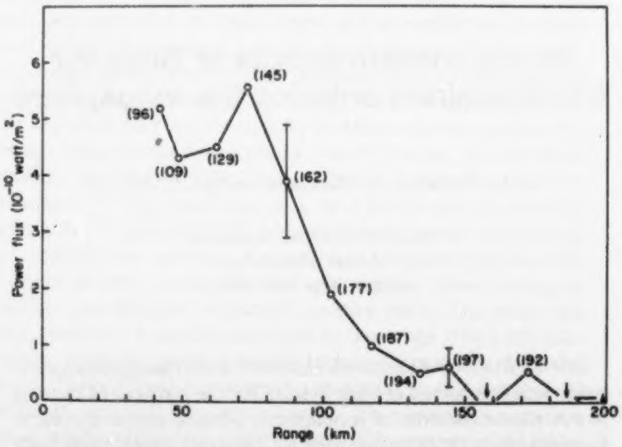

Figure 3. Poynting vector measurements on the sounding rocket as a function of altitude. These are used to determine the overall power injected into the ionosphere.

signal entering the ionosphere was approximately 5 watts. Even though the lower ionosphere severely attenuated the transmitted signal, the remaining signal was still large enough to be amplified and to produce wave-particle interactions.

We thank Don Carpenter and John Katsufrakis for their scientific support at Siple Station. David Matthews was the project scientist for the sounding rocket campaign. Analysis of data from the sounding rockets is supported by National Science Foundation grant DPP 80-23963.

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Particle precipitation and magnetic field variations at Siple Station and in the conjugate region

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Within the last 2 years, 30-megahertz riometers have been installed at the four Bell Laboratories/University of Maryland magnetometer stations in the region of North America (Eastern Canada and Northeastern United States) conjugate to Siple Station. In addition, a 20-megahertz riometer has been installed at the most northern station (Girardville, Quebec), and a 50-megahertz riometer at the next highest latitude station (LaTuque, Quebec). The locations of the Northern Hemisphere stations are shown in figure 1, together with nominal Siple conjugate points as calculated from three separate magnetosphere models. Data have been obtained almost continuously at all of the stations during 1980 and 1981.

The scientific research associated with the magnetic field and the 30-megahertz riometer measurements at Siple Station has concentrated on the relationships between particle precipitation as measured by the riometer and simultaneous magnetic field variations. The high sensitivity of both the magnetometer and the riometer instruments provides an excellent opportunity for studying fast-time variations of low-level changes in particle precipitation and magnetic field variations that occur in opposite hemispheres.

A major recent finding has been the discovery of the generation of hydromagnetic waves by sudden changes in the conductivity of the ionosphere produced by solar flare X-rays (Rosenberg, Morris, and Lanzerotti 1981). This discovery is extremely important in that it has established an additional method for generating ultra-low-frequency waves in the cosmic plasma comprising the Earth's magnetosphere.

Another important set of observations has been obtained concerning the "global" scale of impulsive particle precipitation and concurrent magnetic field variations in conjugate regions. The impulsive riometer variations (measuring impulsive particle precipitation from the magnetosphere into the upper atmosphere) have been observed at Siple to be associated at times with pulses in optical instrumentation (Arnoldy et al. in preparation). Often, the magnetic field variations accompanying the

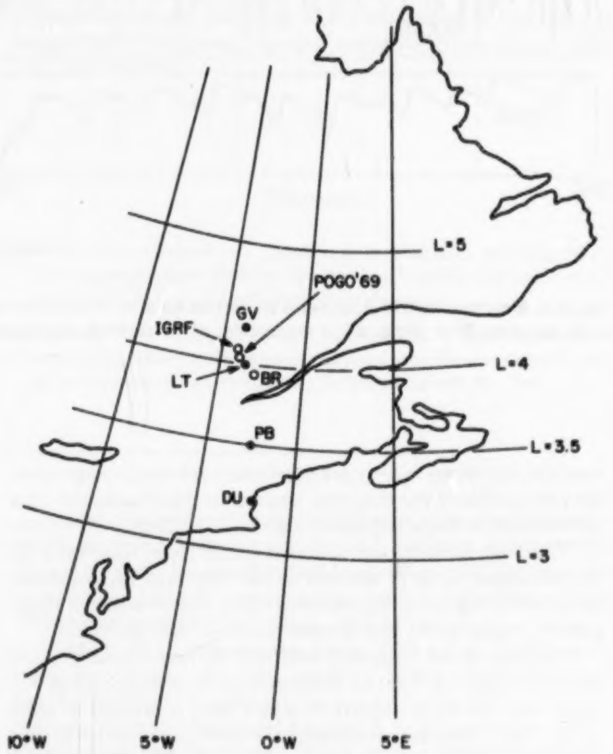

Figure 1. Locations of Northern Hemisphere magnetometer-riometer stations (solid circles) and Siple conjugate points (open circles) calculated from three different magnetic field models. The station locations are: Girardville, Quebec (GV), LaTuque, Quebec (LT), Pittsburg, New Hampshire (PB), and Durham, New Hampshire (DU). The magnetic field models are: Polar Orbiting Geophysical Observatory 1969 model (POGO'69), International Geomagnetic Reference Field (IGRF), and Barish and Roederer model (BR). L = particle drift shell parameter.

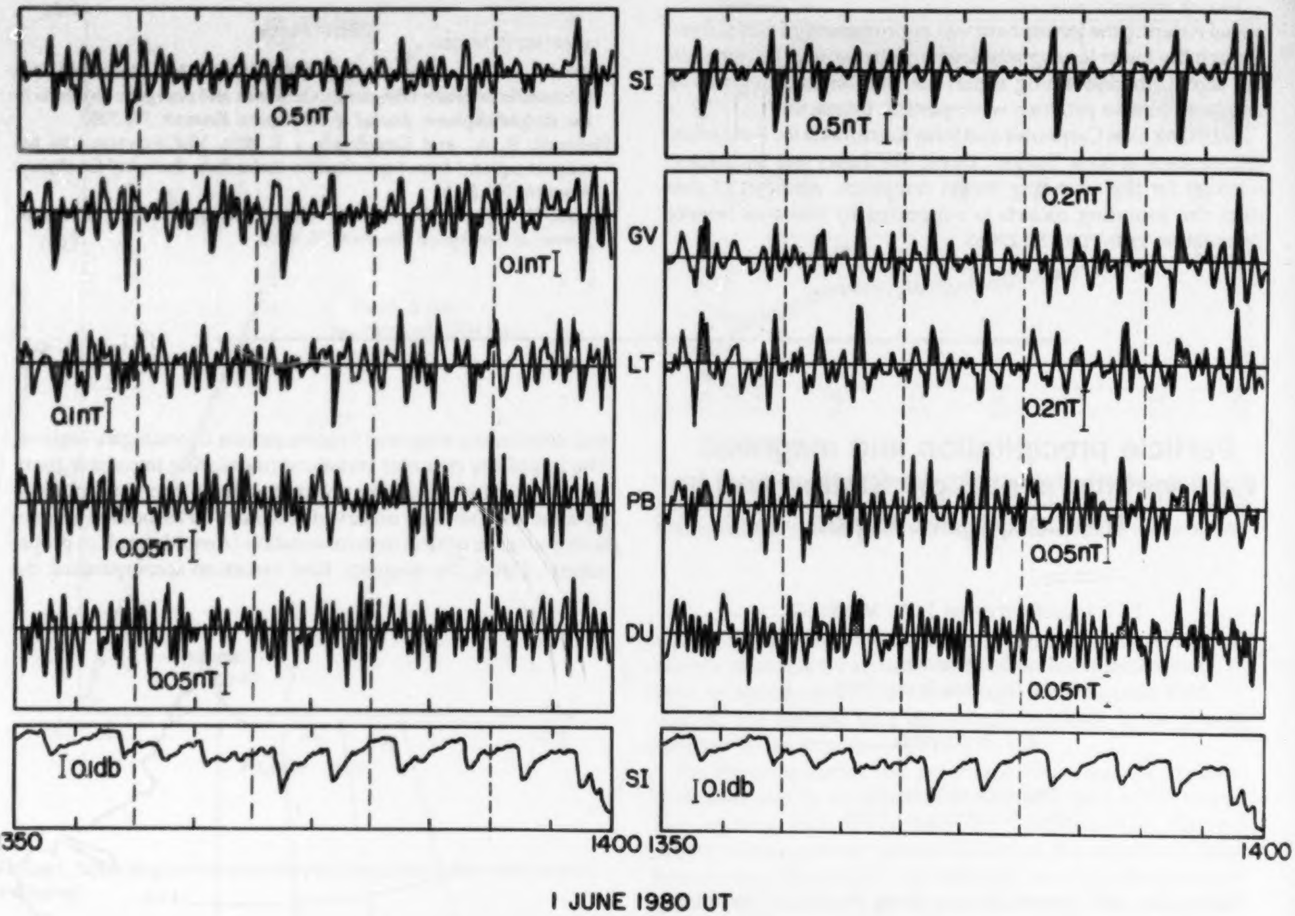

Figure 2. Magnetic field and riometer variations for a 10-minute interval on 1 June 1980. The magnetic field data have been filtered in the band 5–30 seconds. SI = Siple; nT = nanotesla; db = decibel; see figure 1 for explanation of other abbreviations.

riometer variations have a predominant east-west component; the time profile of the magnetic variations often tracks the time dependence of the precipitation pulse as recorded by the riometer. The magnetometer and riometer data at Siple, together with the latitudinal array of stations in the Northern Hemisphere, has given us a good understanding of the spatial extent of these particle precipitation phenomena at subauroral latitudes.

Examples of the magnetic field and riometer variations are shown in figure 2. Plotted at the bottom of both panels of this figure are the 30-megahertz riometer data measured at Siple station for a 10-minute interval (1350–1400 universal time) on 1 June 1980. The sharp onsets of the increases in the absorption of cosmic noise, followed by the slow decreases, are seen throughout the interval.

In the left panel of figure 2 are plotted the H-component (north-south) magnetic variations measured at Siple (top trace) and the Northern Hemisphere stations, from highest to lowest latitude in descending order. In the right panel of the figure are plotted the D-component (east-west) magnetic variations from the same stations. The magnetic field data have been filtered in the band 5–30 seconds. The magnetic field variations at Siple are seen to occur primarily in the east-west component of the magnetic field. In the Northern Hemisphere, the magnetic field impulses also appear primarily in the east-west component, but out of phase with the Southern Hemisphere variations. Some evidence of variations in the north-south component occasionally is obvious in the Northern Hemisphere data as well.

There is evidence of magnetic field variations at least as far south as Pittsburg, New Hampshire (particle drift shell parameter, L, approximately 3.5). Thus, the impulsive precipitation resulting in magnetic field changes is a rather widespread geomagnetic phenomenon, although data for locations farther north than Girardville (L approximatey 4.4) are not available.

The impulsive magnetic field changes and particle precipitation occurred during moderate geomagnetic activity and persisted for more than 4 hours during local morning. The H- and D-component magnetic field variations as well as the riometer signals for an 8-hour interval (0800–1600 universal time) on 1 June are shown in figure 3. The period during which particle

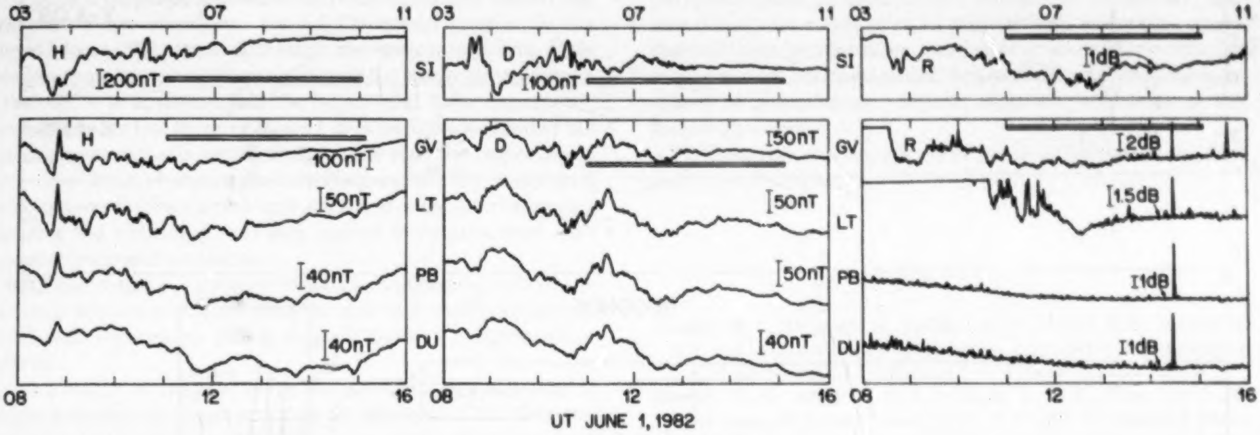

Figure 3. Magnetic field and riometer variations for an 8-hour interval on 1 June 1980, showing the level of geomagnetic activity during the impulsive precipitation events. The left panel shows the north-south (H) component variations, the middle panel the east-west (D) component variations, and the right panel the riometer (R) variations. SI = Siple; nT = nanotesla; dB = decibel; see figure 1 for explanation of other abbreviations.

precipitation and magnetic field variations similar to those in figure 2 occurred are indicated by the horizontal bars. The magnetic field at subauroral latitudes was disturbed at this time, and enhanced particle precipitation, as evidenced by the enhanced absorption of cosmic noise by about 2 decibels, was seen at Siple and over the two most northern conjugate stations.

In summary, the Siple magnetic field and riometer data, together with data from the conjugate hemisphere, illustrate new aspects of particle precipitation and magnetic field fluctuation phenomena at subauroral latitudes. Further study of these data and similar data obtained on other days will provide new insights into the nature of magnetosphere particle precipitation phenomena.

Logistics support for the Bell Laboratories work at Siple Station was provided by the National Science Foundation, Division of Polar Programs. The work at the University of Maryland is supported by National Science Foundation grants DPP 80-12901 and ATM 80-06496.

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Asymmetric magnetic pulsations observed at Siple Station

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As part of a continuing investigation of ultra-low-frequency variations in the Earth's magnetic field, we have investigated a class of irregular magnetic pulsations known as Pi 1 (frequencies in the range .025–1 hertz) using the search coil detector at Siple Station (geographic coordinates, 76°S 84°W).

Although Pi 1 pulsations have been studied for decades with magnetometers of the type employed in this study, the Siple search coil magnetometer has the twin advantages of (1) highly accurate 12-bit digital recording and (2) high time resolution of 20 vector samples per second. This instrumentation has allowed us to observe clearly and quite frequently a class of asymmetric pulsations during geomagnetically disturbed periods.

Shown in figure 1 are normal- (inset) and high-resolution plots of typical but rather "clean" asymmetric pulsations observed during a sustained Pi 1 event on 10 June 1980. The high-amplitude peaks near 80 and 120 seconds in the X (north-south) component appear much more symmetrical in the low-resolution plot than when plotted at full 20 points per second resolution.

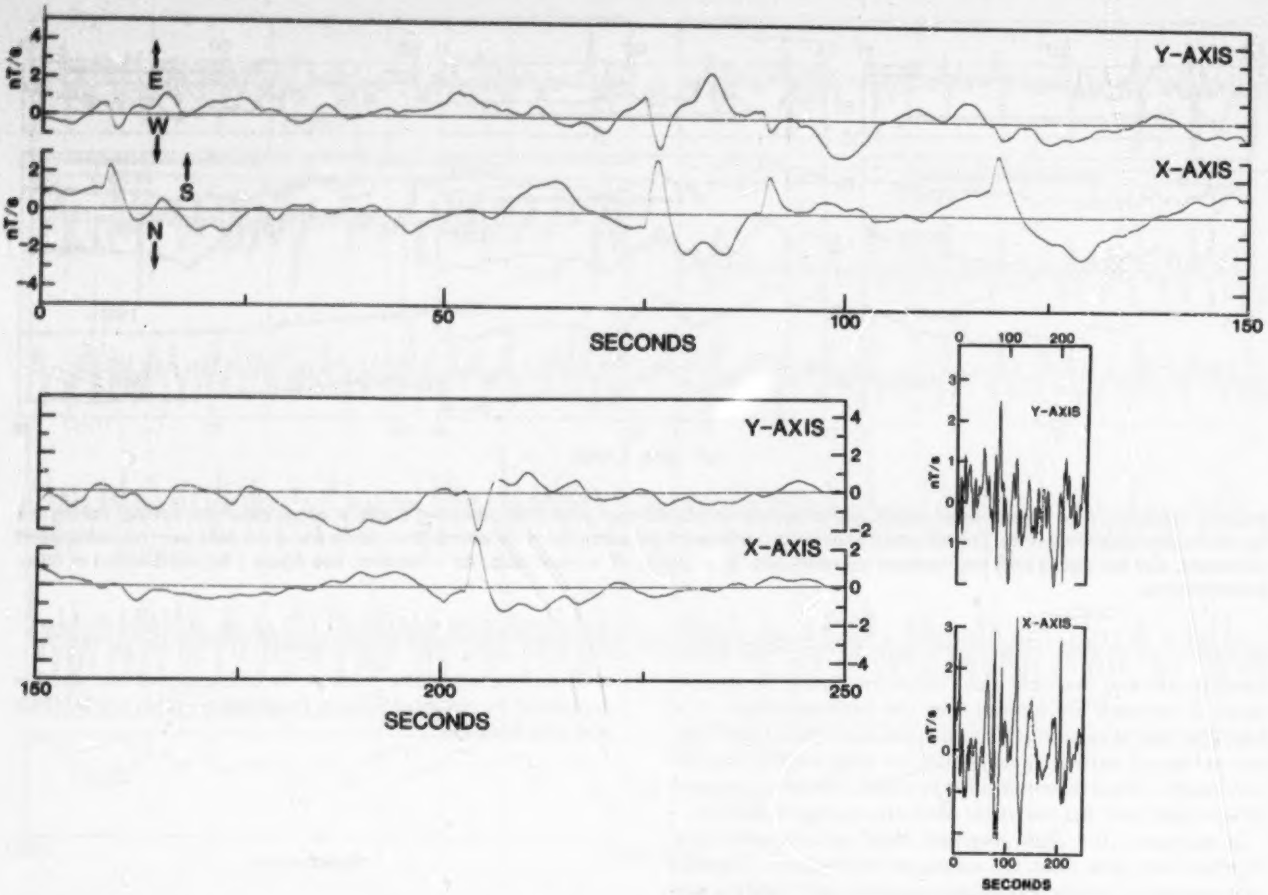

Figure 1. Magnetic field (dB/dt) data from a portion of a sustained Pi 1 event on 10 June 1980. The inset shows a 250-second portion of the event plotted at normal resolution, and the main figure shows full-resolution (20 points per second) data from the digitally sampled search coil magnetometers. nT/s = nanotesla per second.

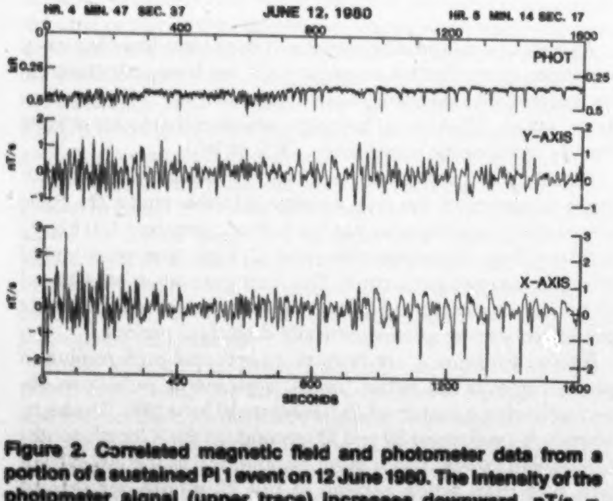

Figure 2. Correlated magnetic field and photometer data from a portion of a sustained Pi 1 event on 12 June 1980. The intensity of the photometer signal (upper trace) increases downward. nT/s = nanotesla per second.

Because a search coil measures the derivative of magnetic induction (dB/dt) the rapid rise and slower fall of the observed asymmetric pulse past the zero level represents a transient, one-sided change and subsequent relaxation in B. We wish to emphasize that the observed pulsations are not waves in the usual sense. Although the pulsation near 200 seconds is followed by a train of more sinusoidal variations in both the X and Y (east-west) components, we have found no other examples where asymmetric pulses appeared to stimulate any sinusoidal magnetic variations.

It was noted by some of us (Arnoldy et al. in preparation) that there was a close association between the prominent, asymmetric pulses and bursts of auroral light as detected at Siple by a narrowband, 4,278-angstrom, zenith-viewing photometer (Mende et al. 1980). To extend that analysis, we studied the 15 largest amplitude Pi 1 events noted during 1980, ranging from 26 March to 19 December. Asymmetric pulsations during all 15 events were visually identified. Although asymmetric pulses in dB/dt sometimes occurred without corresponding optical pulsations, nearly every optical pulsation was associated with a magnetic pulsation approximately 1 second later.

Figure 2 displays simultaneous photometer and search coil magnetometer waveforms for a 1,600-second interval during the 12 June 1980 event. Although the compressed time scale makes examination of the waveform of the magnetic pulsations difficult, it is apparent that the largest and most asymmetric pulsations are like those of figure 1. The background level of the photometer signal is significantly higher near the beginning of the time interval shown and decreases gradually. Individual photometer pulses are no larger at the end of the interval shown than at the beginning, but they appear to be associated with greater magnetic variations.

All the major photometer pulses in the second half of the interval shown, and most minor ones as well, clearly are associated with asymmetric pulses in the X and/or Y components of dB/dt.

The origin of irregular magnetic pulsations (pi) observed at high latitudes has been a matter of controversy for decades. Observations of these and other asymmetric pulsations, and especially the close relationship between magnetic field changes, optical pulsations, and changes in ionospheric electron density (Arnoldy et al. in preparation), lead us to suggest that this class of pulsations originates at ionospheric altitudes and may be a rather common, but probably not the exclusive, source of auroral-zone irregular magnetic pulsations in this frequency range.

This research was supported by National Science Foundation grant DPP 79-23294.

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Energy spectrum of precipitating electrons during an artificially triggered wave event

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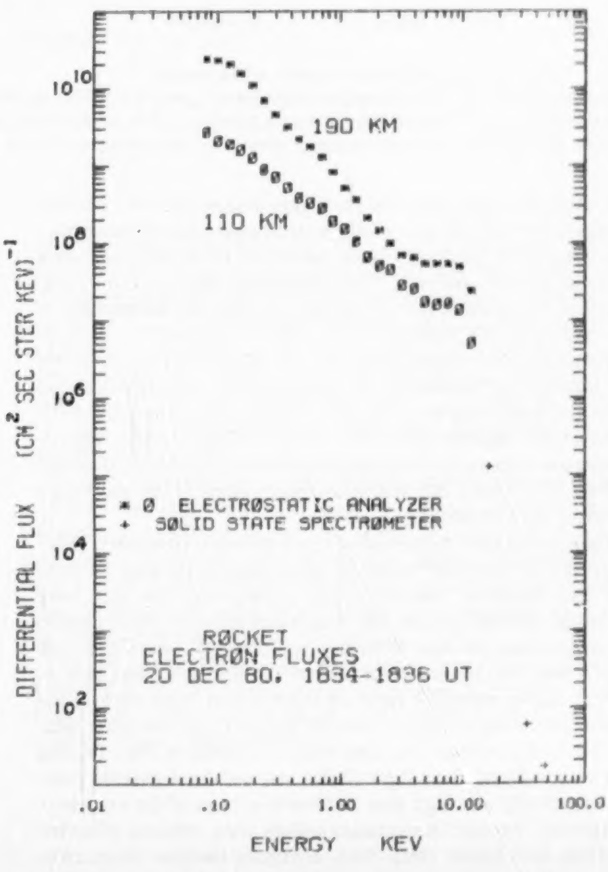
The Nike-Tomahawk rocket payloads launched at Siple Station during the 1980–81 magnetospheric physics campaign included comprehensive energetic electron spectrometers. Results from the solid-state units, which measured electrons of energy greater than 16 kiloelectronvolts, are discussed in a companion article (Siren and Matthews, *Antarctic Journal*, this issue). Here I discuss the results from the electrostatic analyzers for energies between 0.1 and 16 kiloelectronvolts and give a summary spectrum.

Portions of the data in each rocket roll period were contaminated by solar ultraviolet photons. These portions are clearly distinguishable from the good data and are not used.

On rocket flight 18.204 (20 December 1980) there is a moderately intense low-energy flux which shows altitude-dependent absorption. The figure shows preliminary differential energy spectra from this flight averaged over several seconds. Three points from the solid-state detector are included; higher energies have been omitted to avoid excessive scale compression. The measurements actually cover 4 decades in energy and 11 in differential flux.

Several features of these data merit discussion. There is no obvious correlation between the electron fluxes and simultaneously observed wave events, whether the latter were naturally or artificially triggered. This is not surprising because the waves can spread out hundreds of kilometers horizontally from



Spectrum of precipitating electrons at two altitudes. Solid-state detector points (+) are from the lower altitude. The differential flux values indicate the number of electrons per unit solid angle (steradian) and unit energy (kiloelectronvolt) passing through 1 square centimeter in 1 second. UT = universal time.

the interaction region high above the rocket, whereas electrons are constrained to remain close to the near-vertical magnetic field line passing through that region.

The search for correlations is continuing.

The spectrum looks very like what is often observed in diffuse aurora. The intense part of it occurs at energies too low to produce radio-wave absorption as seen on a riometer. No absorption was in fact seen at Siple.

Finally, the very sharp break near 18 kiloelectronvolts seen in the figure and discussed in the companion article suggests a sharp maximum for the magnetospheric electrostatic potential through which the observed electrons presumably were accelerated.

This work was supported by National Science Foundation grant DPP 80-13722. Vehicle and telemetry support and related field operations were provided by the National Aeronautics and Space Administration, Goddard Space Flight Center.

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Siren, J. C., and Matthews, D. L. 1982. Energetic electron observations by high-altitude rockets launched from Siple Station. *Antarctic Journal of the U.S.*, 17(5).

Energetic electron observations by high-altitude rockets launched from Siple Station

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During the Siple-Roberval conjugate magnetospheric physics campaign in 1980–81, three fully instrumented ionospheric plasma diagnostic payloads were launched by Nike-Tomahawk rockets. Figure 1 shows a Nike-Tomahawk launch. (For a summary of the goals of the campaign and the instrumentation of the payloads, see Matthews 1981.) The University of Maryland experiment on each payload consisted of a low-energy analyzer for measuring electrons of 100 electronvolts to 27 kiloelectronvolts and solid-state detectors for measuring electrons of greater than 16,000 electronvolts. The lower energy electron experiments are discussed in a companion article (Matthews, *Antarctic Journal*, this issue); this article discusses some of the solid-state detector data obtained.

Each instrument consisted of three identical detectors, viewing at 30°, 70°, and 110° from the (spinning) rocket axis. Because the two detectors making larger angles with the axis were strongly affected by solar ultraviolet radiation, we have chosen to concentrate on data from the "uplooking" detector. It was much less affected by solar radiation. We have been able to obtain useful energetic electron information from each of the three rocket flights [1719 universal time (UT) 12 December 1980; 1732 UT 20 December 1980; and 1822 UT 10 January 1981]. During the second flight, NASA flight 18.204, natural wave-particle interaction activity was high and multi-hop echoes of the very-low-frequency "Jupiter" transmitter pulses were evident (Kintner, Brittain, and Kelley 1981). Also, energetic electron count rates showed the most temporal variation of any of the three flights. The remainder of this article describes the energetic electrons observed during this flight.

Figure 2 is a plot of energetic electron count rates (linear scales) for the entire interval during which the experiment returned meaningful data. The various channels represent different energy ranges, as given in the table. The experiment was turned on at 1733:42 UT (altitude 89 kilometers) and functioned through apogee at 1736:10 (189 kilometers) until reentry at 1738:33 (93 kilometers). The most significant feature of the data

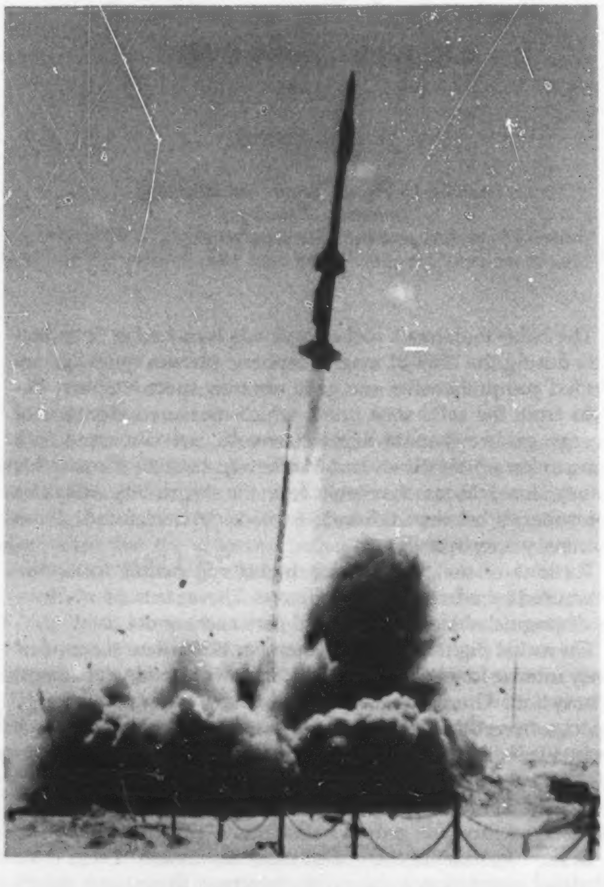

Figure 1. Launch of Nike-Tomahawk from Siple Station. Thermal-control black plastic sheeting covering the rocket strips off during ascent. (Photograph by J. Siren)

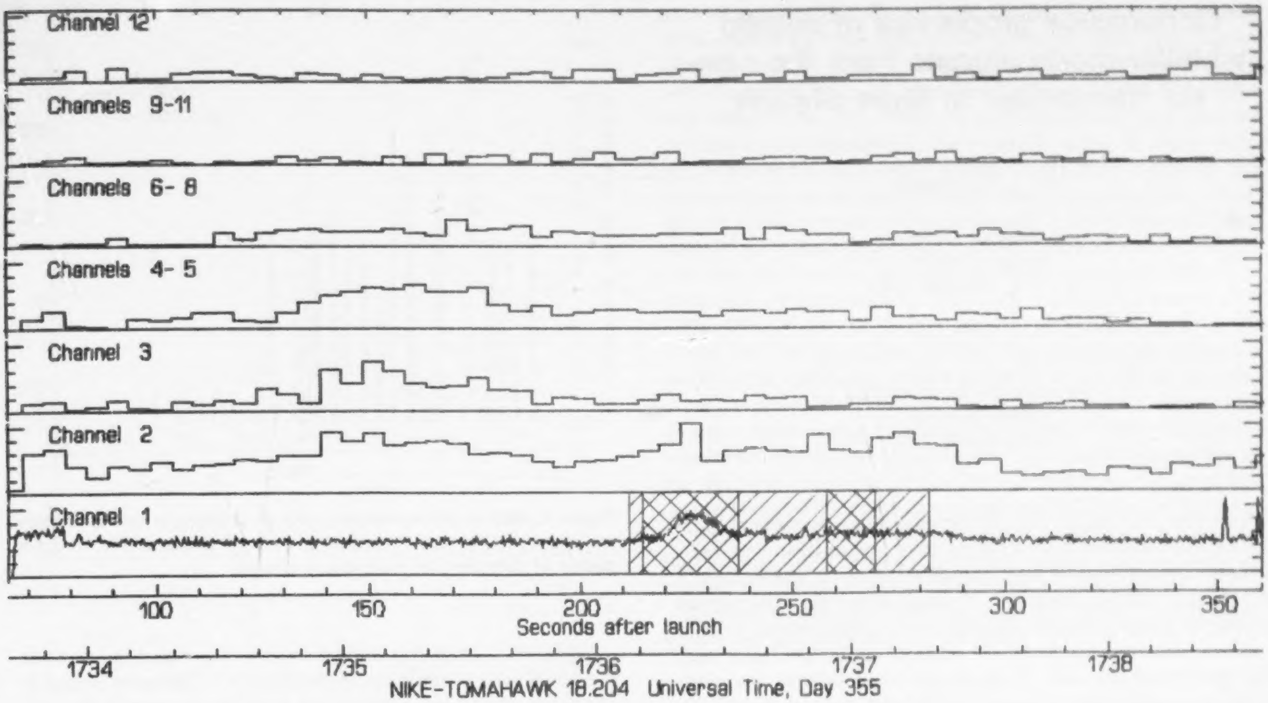

Figure 2. Energetic electron count rates (uplooking detector), 20 December 1980. Channels 3 and above: 10 counts per second full scale, accumulated for 5 seconds; channel 2: 20 counts per second full scale, accumulated for 5 seconds; channel 1: 6,000 counts per second full scale, accumulated for 0.32 seconds. Single-hatched areas: possible solar contamination (see text); cross-hatched areas: definite solar contamination.

was the very much higher count rate in the lowest energy channel (channel 1; 16–32 kiloelectronvolts) compared with the higher energy channels. This is indicative of a sharp break in the electron energy spectrum. By comparing the electron count rates in channel 1 and channel 2, we estimate that the break was no higher in energy than 18 kiloelectronvolts, and may have been lower. This is similar in nature to auroral electron energy spectra (see companion article, Matthews 1982). In channels 2 through 8, electron count rates tended to be higher before the midpoint of the flight than after. In channel 9 and above, count rates were simply too low to say whether there was any significant temporal variation. The variations in channels 2 through 8 mainly were uncorrelated with channel 1. However, for about 12 seconds after experiment turn-on (when the rocket was still nearly directly over Siple) channel 1 did show a significantly higher count rate than later in the flight. It appears, from the raw data, that this excess was parallelled simultaneously in channels 2 through 5.

Solid-state detector energy levels

Channel	Energy (Kiloelectronvolts)
12	>850
11	565–850
10	375–565
9	250–375
8	193–250
7	147–193
6	113–147
5	85–113
4	62–85
3	47–62
2	32–47
1	16–32

It has not been possible to identify correlations between these energetic electron count rates and the various, complex wave phenomena observed during the flight. (However, it may be that the characteristic type of electron energy spectrum observed during this flight is a necessary condition for the occurrence of multi-hop echoing of Jupiter transmissions, such as was prominent throughout the flight.)

This work was supported by National Science Foundation grant DPP 80-13722. Vehicle and ground station support were provided by National Aeronautics and Space Administration-Goddard Space Flight Center.

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Occurrence properties of ducted whistler-mode signals from the new VLF transmitter at Siple Station

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Very-low-frequency (VLF) transmitting experiments at Siple Station are designed to investigate wave propagation and interactions between waves and energetic particles in the Earth's magnetized plasma envelope, or magnetosphere. The signals propagate along geomagnetic-field-alined paths between hemispheres, crossing the magnetic equator at several Earth radii (R_E) geocentric distance. A significant improvement in experimental capability was achieved in 1979 with the installation of a new transmitter, Jupiter, which is capable of operating at higher power (approximately 7 decibels) than the previous system, Zeus, and also is more flexible with respect to modulation. This article reports on occurrence features of the signals in 1980 and makes some comparisons with results from the Zeus transmitter.

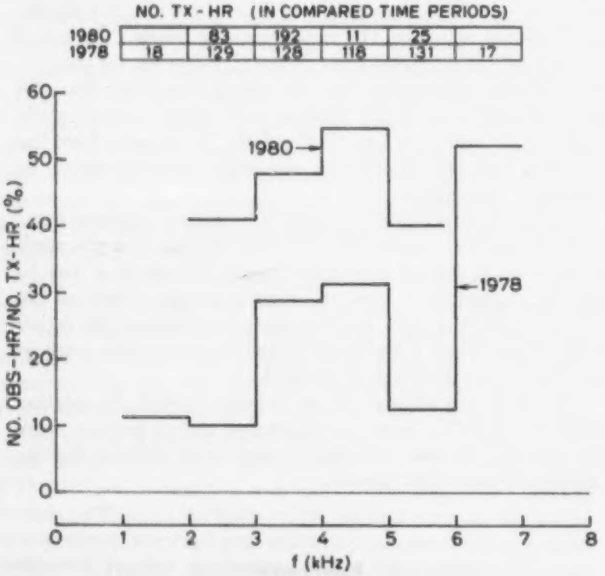

Figure 1. Percentage of Siple transmitting hours (NO. TX-HR) during which magnetospherically propagated, very-low-frequency (VLF) whistler-mode signals were detected at ground stations (NO. OBS-HR) as a function of transmitter frequency (f). Results from the new transmitter, Jupiter, in 1980 are compared with results from the previous system, Zeus, in 1978.

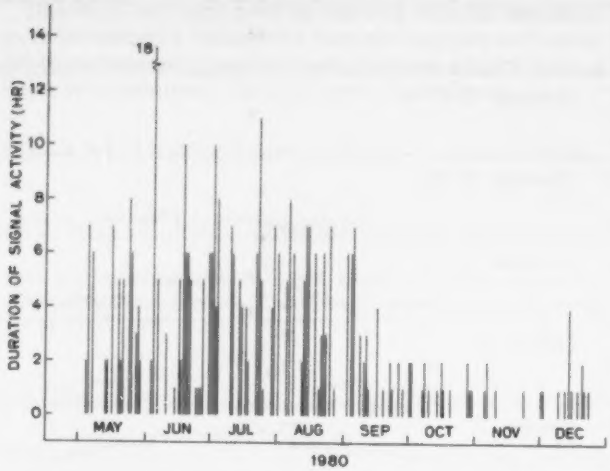

Figure 2. 1980 seasonal variation of the duration (in hours) of Siple whistler-mode signal detection at ground stations. The longest period of detection on each day is shown.

Major changes in operating frequency have been made since the initial transmitting experiments in 1973. The most favorable range for signal propagation has been found to lie below approximately 4 kilohertz, despite the fact that the efficiency of the present 21.4-kilometer-long dipole antenna falls off sharply with decreasing frequency in this range.

Figure 1 shows a comparison of Zeus in 1978 and Jupiter in 1980 in terms of percentage of successful transmissions as a function of operation frequency. Success was determined by comparing the number of hours during which whistler-mode signals were observed at the conjugate station at Roberval, Canada, or in the two-hop echo mode at Siple, with the total hours of transmissions. The data represent scheduled activity in the approximate period 0300–1100 local time.

In both years, relatively large numbers of transmissions in the 2–4 kilohertz range were made. Within this range the overall success ratio was 46 percent in 1980, compared with 20 percent in 1978. Furthermore, the 1980 success rate remained relatively high as frequency was decreased below 3 kilohertz, while the 1978 data showed a sharp drop in the 2–3 kilohertz range.

The 1980 data provided exceptionally good diurnal coverage during the austral winter. The expected nightside minimum and dawn maximum in signal activity were defined in much better detail, and a secondary peak in activity centered near 1900 local time was defined for the first time. This peak may be associated with the duskside bulge in the plasmasphere, at which the plasmapause radius increases rapidly with local time (Carpenter 1966). The bulge effect increases the probability that the preferred region of Siple propagation, the outer plasmasphere, will overlie the station. It may also cause drifting low-energy electrons to penetrate the plasmasphere and to act as a fresh source of resonant wave-particle interactions and associated amplification of VLF waves.

Seasonal effects, attributed in part to changes in ionospheric absorption of the transmitted waves, were well defined in the 1980 data. The importance of the austral winter is illustrated in figure 2, which shows the duration (in hours) of detected signal activity for May–December 1980. The longest sequence for each universal time day is represented. In November and December,

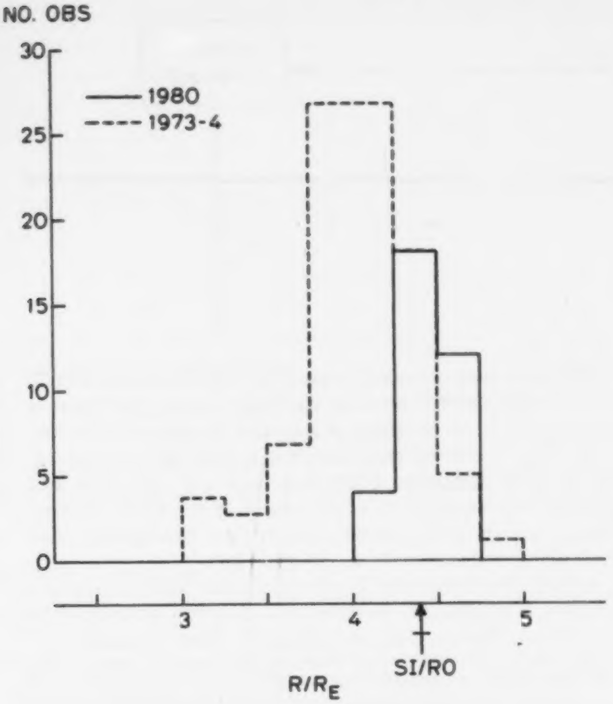

Figure 3. Distribution of geocentric equatorial radii of the field-aligned paths of Siple signal propagation during 21 periods of strong signal activity during the 1980 austral winter. The radius corresponding to field lines overhead of Siple/Roberval (SI/RO) at approximately 100 kilometers altitude is indicated. Dashed lines show data from periods in 1973–74, as reported by Carpenter and Miller (1976).

most of the reception periods were brief, lasting no more than 1 hour, while in winter most of these periods were longer than 1 hour, and many exceeded 5 hours.

Using whistler techniques, we analyzed the location of Siple signal paths during 21 periods on 12 days of outstanding signal activity in mid-1980. Figure 3 shows the distribution of equatorial radii of the Siple signal paths for these cases. Also shown (dashed line) is a histogram for path analyses representing July–August 1973 and September–November 1974 (Carpenter and Miller 1976). The range of path equatorial radii for 1980 projects to an ionospheric north-south range of order ±150 kilometers at 100 kilometers altitude above Siple/Roberval. The concentration of the better defined ducted signal paths within this relatively narrow range centered on the station confirms earlier conclusions regarding the overriding importance of the injected wave level in achieving temporal wave growth and in triggering of emissions by the Siple signals (Carpenter and Miller 1976; Helliwell, Carpenter, and Miller 1980).

The 1980 results can be modeled as occurring on paths approximately overhead of Siple/Roberval at 100 kilometers. The principal effects of changes in transmitter frequency, then, were changes in the energy of interacting magnetospheric electrons rather than changes in path location. The results suggest that as the radiation capability of the Siple system is increased at frequencies near 2 kilohertz through planned changes in the longwire antenna configuration and in other parts of the transmitting system, the energy range of the magnetospheric particles probed by the system will be increased significantly.

This work was supported by National Science Foundation grants DPP 80-22282 and DPP 80-22540.

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Services, support, other

Polar Research Board antarctic-related activities, June 1981–June 1982

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The Polar Research Board (PRB),* established in 1958 by the National Academy of Sciences (NAS), advises Federal agencies on research in the polar regions and represents the NAS in activities of the Scientific Committee on Antarctic Research (SCAR) of the International Council of Scientific Unions. During the past year, the Board met twice, and its committees and *ad hoc* study groups held 22 meetings. The Board also published seven reports, four of special studies and three annual reports. The primary activity continued to be preparation of a series of reports in the series "Polar Research—A Strategy," through which the Board is developing an overall strategy for polar research to the end of the century. Work continued on studies related to polar biomedical research, permafrost, the role of the polar regions in climatic change, snow and ice research, and ice segregation and frost heaving (see *Antarctic Journal of the U.S.*, 16(5), 225-226). Board members also planned for U.S. participation in the 17th meeting of SCAR and took part in meetings of SCAR Working Groups and Groups of Specialists. More than 150 scientists from universities, government, and industry participated in the work of the Board and its subunits over the past year. The Board attempts to maintain balance over the long term between its arctic and antarctic activities; this article reports on only the antarctic portion of its program.

International activities. U.S. delegates to SCAR are James H. Zumberge and PRB Chairman Charles R. Bentley, with Board member Campbell Craddock serving as SCAR delegate for the International Union of Geological Sciences. During the past year, two U.S. scientists served as convenors, and another as deputy convenor, of SCAR Groups of Specialists. In addition, 12 U.S. scientists served on SCAR Working Groups, 2 of them as secretary and 1 as chairman of a special Working Group Subcommittee. The Board published two annual reports for SCAR, one on U.S. antarctic research activities in progress and planned and the other on investigations in the earth sciences. Figure 1 depicts U.S. representation in SCAR, and figure 2, SCAR structure, interrelationships, and products.

A major concern of the Board during the past year was developing a position on matters to come before SCAR at its 28 June–11 July 1982 meeting in Leningrad. These included:

- Role of the proposed BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks) Secretariat *vis-a-vis* implementation of the new Convention on the Conservation of Antarctic Marine Living Resources;
- Management of data from the First International BIOMASS Experiment (FIBEX) and plans and schedule for its successor, SIBEX (Second International BIOMASS Experiment);
- The approach adopted by the Group of Specialists on Antarctic Climate Research in developing an international research program in this field;
- Proposed marine Sites of Special Scientific Interest at Chile Bay, Greenwich Island, and Port Foster, Deception Island; and
- An increase in SCAR dues and a proposed formula for projecting future increases over a period of several years.

In addition to these activities, meetings of the Working Groups on Biology, Upper-Atmosphere Physics, and Logistics were scheduled, and a symposium on antarctic logistics was organized.

PRB member Robert H. Rutford served as convenor of the SCAR Group of Specialists on Environmental Implications of Possible Mineral Exploration and Exploitation in Antarctica, thus continuing the Board's involvement and concern with SCAR activities addressing this problem. The Group prepared a new draft report, a followup to the previous PRB-supported studies, and will develop a second draft on the basis of reactions to the preliminary report and informal interaction during the SCAR meeting in Leningrad.

Following the data-collection phase of FIBEX in January and February 1981, in which 17 ships from 10 countries took part, a

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**Polar Research Board members:* Charles R. Bentley (chairman), Vera Alexander, Jerry Brown, Campbell Craddock, Albert P. Crary, Joseph O. Fletcher, Richard M. Goody, Arnold L. Gordon, Hans O. Jahns, Philip L. Johnson, Arthur H. Lachenbruch, J. Murray Mitchell, Jr., Chester M. Pierce, E. Fred Roots, Juan G. Roederer, Robert H. Rutford, and Donald B. Siniff. *Ex-officio members:* James H. Zumberge (U.S. delegate to SCAR), M. F. Meier (chairman, Committee on Glaciology), and Jerry Brown (chairman, Committee on Permafrost). *PRB staff:* W. T. Hushen (executive secretary), Bertita E. Compton (staff officer since June 1982), and Muriel A. Dodd (administrative assistant).

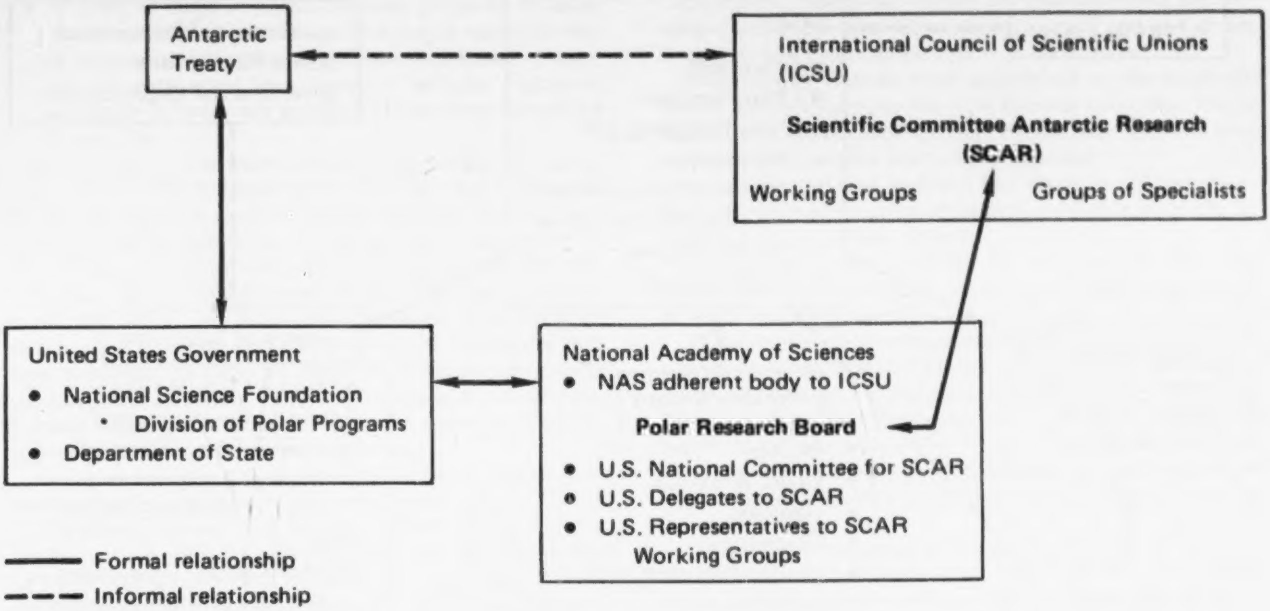
Antarctic Treaty
International Council of Scientific Unions (ICSU)
Scientific Committee Antarctic Research (SCAR)
Working Groups
Groups of Specialists
United States Government
• National Science Foundation
• Division of Polar Programs
• Department of State
National Academy of Sciences
• NAS adherent body to ICSU
Polar Research Board
• U.S. National Committee for SCAR
• U.S. Delegates to SCAR
• U.S. Representatives to SCAR Working Groups
Formal relationship
Informal relationship

Figure 1. United States representation in the Scientific Committee on Antarctic Research (SCAR).

FIBEX Workshop took place in Hamburg, where the data currently are housed. Some 30 scientists representing 11 countries participated. The SCAR Group of Specialists on Southern Ocean Ecosystems and Their Living Resources, which advises on the BIOMASS Program, met in May 1982 to consider the future of the BIOMASS Program and to develop scientific priorities for SIBEX. At the request of the National Science Foundation, the Board selected and supported U.S. scientists to participate in international scientific and planning meetings related to BIOMASS.

A steering committee of the PRB chaired by C. B. Bull (who is U.S. member and secretary of the SCAR Working Group on Glaciology) organized the Third SCAR/International Glaciological Society (IGS)/Inter-Union Commission on Snow and Ice (ICSI) Symposium on Antarctic Glaciology, held in Columbus, Ohio, 7–12 September 1981. The *Annals of Glaciology* will publish the proceedings of the symposium.

Domestic activities. In August 1981, the PRB published *An Evaluation of Antarctic Marine Ecosystem Research,* the report of a committee it established jointly with the Ocean Sciences Board to consider research opportunities in the southern ocean, targets for U.S. contributions to the BIOMASS research effort, and management and coordination of the international research program. The report emphasizes the need for interdisciplinary approaches that combine the expertise of physics and biology. It has been cited as a model for research planning in regions other than the Antarctic. A number of Federal agencies have indicated that they are acting on its recommendations.

The PRB also published, in February 1982, *Study of the Upper Atmosphere and Near-Earth Space in Polar Regions: Scientific Status and Recommendations for Future Directions.* This report notes that Antarctica is a unique location for certain kinds of experiments and recommends that the United States urge SCAR to bring together scientific representatives of interested member nations to review upper-atmosphere and near-earth space programs in Antarctica and to develop plans for the future.

Following a White House Memorandum of 5 February 1982 that called for maintenance of an active and influential U.S. presence in Antarctica, including the conduct of scientific activities in major disciplines, the National Science Foundation renewed discussions with the Board about the need for an explicit statement of the basic science that should be done, the role of antarctic research in fostering a better understanding of national and global environmental concerns such as climate, and the level of effort required to maintain a vigorous and high-quality polar research program. Subsequently, the Board agreed to undertake a study to outline a core program of antarctic research. The study is expected to:

- Identify the scientific disciplines that uniquely benefit from continuing research in Antarctica;
- Identify the most important research questions and opportunities in each of these disciplines;
- Estimate the minimum level of effort required to pursue a meaningful research program addressed to each question/opportunity; and
- Evaluate the relative importance and likelihood of success among the research efforts identified.

To establish priorities, research will be assessed in terms of scientific merit (intrinsic value, uniqueness to Antarctica, etc.), relevance to resources/environmental issues, international contributions, and constraints. By letter and questionnaire, the Board will alert the antarctic research community and other U.S. scientists to the study and request their views on the components of a core program. This is expected to be a major effort of the Board over the next year.

The work described in this report was supported by two National Science Foundation grants (DPP 79-13076 and DPP

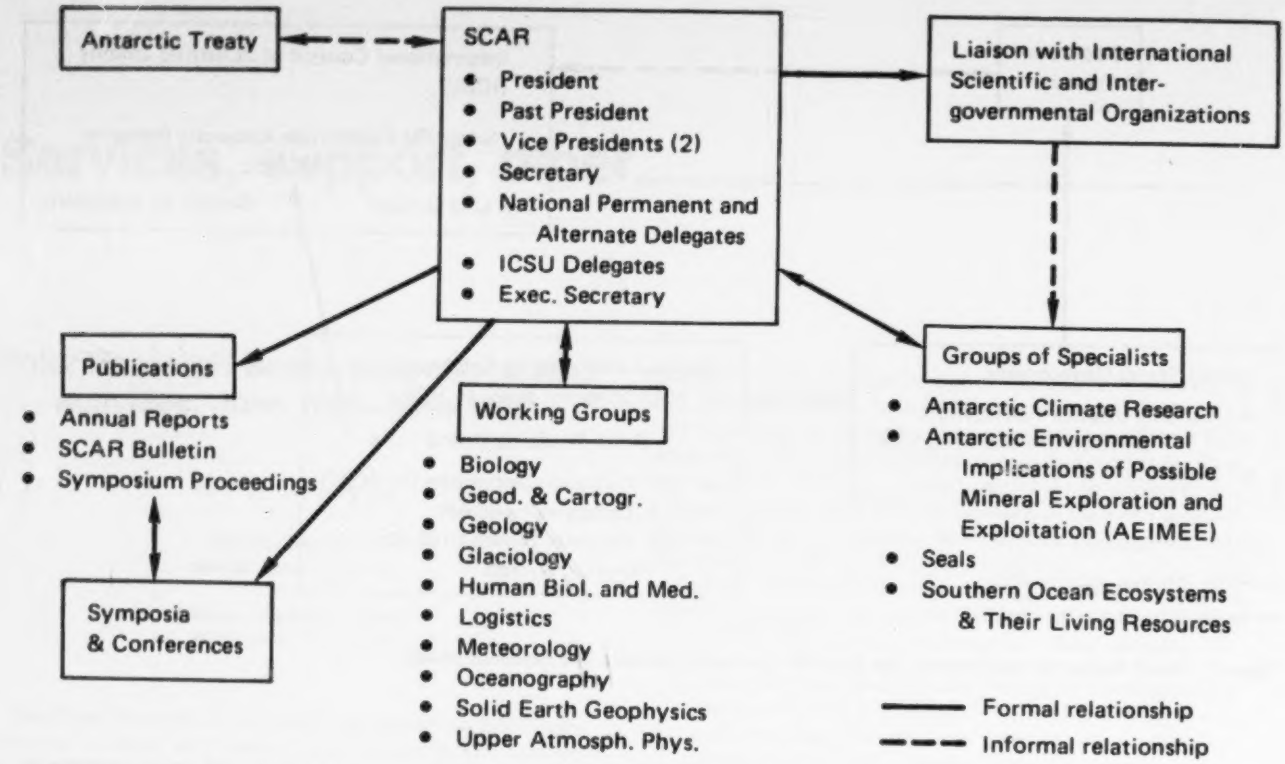
Antarctic Treaty
SCAR
• President
• Past President
• Vice Presidents (2)
• Secretary
• National Permanent and Alternate Delegates
• ICSU Delegates
• Exec. Secretary
Liaison with International Scientific and Inter-governmental Organizations
Publications
• Annual Reports
• SCAR Bulletin
• Symposium Proceedings
Working Groups
• Biology
• Geod. & Cartogr.
• Geology
• Glaciology
• Human Biol. and Med.
• Logistics
• Meteorology
• Oceanography
• Solid Earth Geophysics
• Upper Atmosph. Phys.
Groups of Specialists
• Antarctic Climate Research
• Antarctic Environmental Implications of Possible Mineral Exploration and Exploitation (AEIMEE)
• Seals
• Southern Ocean Ecosystems & Their Living Resources
Symposia & Conferences
Formal relationship
Informal relationship

Figure 2. Scientific Committee on Antarctic Research (SCAR)—organization and interrelationships.

79-27065), with contributions from the National Oceanic and Atmospheric Administration, the Office of Naval Research, and the Department of Energy, and by grants from the Department of Energy, the Department of Defense, the Marine Mammal Commission, and the Andrew W. Mellon Foundation. Additional information can be found in *Polar Research Board Annual Report 1981 and Future Plans*, which is available from the Polar Research Board.

Mapping operations in Antarctica

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The U.S. Geological Survey (USGS), in cooperation with the National Science Foundation (NSF) compiles and publishes base maps of selected areas of Antarctica. These maps are prepared in support of NSF-sponsored scientific research projects of the United States Antarctic Research Program.

Maps of Antarctica published since 1965 are subdivisions of the International Map of the World (IMW) system and use symbols recommended by the Scientific Committee on Antarctic Research (SCAR). Four series of maps are available:

- A series at 1:50,000 scale having a basic contour interval of 50 meters and supplementary contour intervals of 25 meters. These maps cover 15 minutes of latitude and 60 minutes of longitude and measure 56 by 69 centimeters.
- A series of shaded relief maps at 1:250,000 scale having a basic contour interval of 200 meters. Sheet sizes are 66 centimeters by 76, 84, or 91 centimeters, depending on latitude.
- A series of shaded relief maps at 1:500,000 scale covering coastal areas of Wilkes Land and Enderby Land and having a contour interval of 305 meters (1,000 feet) and supplemental 152-meter (500-foot) contours.

- A series of maps at 1:1,000,000 scale produced in accordance with IMW specifications. Each map is named for one of the principal natural features in the area it encompasses. All the maps cover four degrees of latitude; degrees of longitude covered vary as meridians converge toward the South Pole.

In addition to these maps, the USGS has published a sketch map series at 1:500,000 scale having shaded relief but no contours, and Landsat satellite image maps at 1:500,000 and 1:1,000,000 scales. Future satellite image maps will replace the sketch maps and will provide added coverage at 1:250,000 scale.

To date, ninety 1:250,000-scale topographic maps covering about 968,000 square kilometers and eight 1:500,000-scale sketch maps covering about 982,000 square kilometers have been published. In addition, eight 1:50,000-scale topographic quadrangles of an area in the dry valleys have been published. Landsat imagery and weather satellite imagery is being acquired for additional satellite imagery maps.

As in past years, in 1981–82 the USGS fielded an austral summer team and a winter team. This year one individual, Thomas E. Henderson, served as a member of both parties. He and William L. Cain staffed the summer party from early November 1981 until mid-January 1982. At that time, Cain returned to the United States and Henderson traveled to South Pole Station to join Kathy Covert, who had arrived there in mid-November. That team will be relieved in November 1982.

The missions of the USGS 1981–82 austral summer field project were:

- To improve and to increase the density of mapping control in northern Victoria Land as part of a major scientific expedition into that area;
- To provide assistance to New Zealand Antarctic Research Program surveyors in obtaining Doppler satellite control, and;
- To relocate and remonument the geographic South Pole.

Sixteen Doppler satellite positions were established, ranging from Mount Murchison in the south to Mount Burch near the northern coast, and from Cape Hallett in the east to the Outback Nunataks in the west. Thirty-two peaks were intersected, mostly in the western area. An important traverse station at Cape Hallett, established during the 1961–62 season and destroyed sometime after 1964, was resurveyed and tied to sea level with tide observations over a 24-hour period.

Five Doppler stations were established in the McMurdo Sound dry valleys region for New Zealand surveyors. Two of these points, Miers Valley and Cape Royds, have ties to sea level with tide observations over a 36-hour period.

An old triangulation station at Hut Point near Vince's Cross was occupied with Doppler equipment and tied to sea level with readings over a 24-hour period.

Measurements were made for the location of the true geographic South Pole using extrapolated geographic coordinates of the South Pole Station geoceiver antenna.

At the request of the station manager, the USGS team is preparing a detailed "as-built" site plan of the station area. This has not been done since initial construction in 1974–75, and since then a number of permanent buildings, antennas, cables, and towers have been added. The necessary survey work carried over past station closing in mid-February, and the final drawings were expected to be available when the station opened in November 1982.

USGS winter personnel at South Pole Station continued to track Navy Doppler satellites and to transmit the data acquired to the United States. In addition, they operated and maintained the USGS seismograph equipment at the station. Because of its unique location, this station is the only one that can provide essential azimuth control for many epicenter solutions occurring in southern latitudes. It is a vital link in the Worldwide Standardized Seismograph Network.

The USGS maintains an antarctic cartographic and aerial photography library and provides support to investigators, both foreign and domestic, who need such maps and photographs. All U.S. aerial negatives of Antarctica and both foreign and U.S. maps are on file and available to qualified researchers. Appointments to visit the facility can be made by telephone (703/860-6241). Copies of control data referred to in this report (i.e., coordinates, physical identification, and photo identification of each station) can be obtained from the NSF or USGS.

These projects were funded by National Science Foundation grant DPP 81-12853.

Antarctic Research Series

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Since 1963, the Antarctic Research Series has been the publication medium for reports on antarctic research that are too lengthy or too comprehensive for inclusion in standard disciplinary journals. The series encourages collections of papers on specific geographic areas as well as volumes that focus on particular disciplinary problems. Marine biology, oceanology, meteorology, upper atmosphere physics, terrestrial biology, snow and ice, human adaptability, and geology have been covered by the series.

To speed publication and to increase distribution by keeping costs down, individual papers are published as they are completed. Each paper is assigned to a thematic volume. Usually, two or three closely related papers are published in a softcover "minibook." Individuals may purchase the separate minibooks or subscribe to a volume. Libraries with standing orders receive the individual papers as they are published and bind them when all papers within a specific volume have been published.

All papers in the series are subjected to peer review. After scientific review and revision are complete, papers are reviewed by an American Geophysical Union (AGU) copy editor for style, consistency, and general publication requirements. After the author has confirmed that changes made by the copy editor are satisfactory, the paper is typed to strict AGU specifications. Authors who have access to automatic typewriters or word processing equipment are urged to undertake the preparation of the final typescript. Special rates for reprints are available for authors providing final typescripts to AGU specifications.

Individuals wishing to develop a thematic volume for the series must prepare a proposal for review by the series' Board of Associate Editors. Authors of individual papers may wish to contact a Board member through AGU to determine whether a volume in a specific field is in process and whether the work is appropriate for inclusion.

Current Board members are Charles R. Bentley (chairman), Robert H. Eather, David H. Elliot, Dennis E. Hayes, Louis S. Kornicker, Hans H. Lettau, and Bruce Parker. The Board recently has approved volumes on the geology of northern Victoria Land and on marine biology. Several other volumes are being developed and will receive formal review at the next meeting of the Board. Nine other volumes are in production.

Proposal forms and information for contributors are available from AGU, 2000 Florida Avenue, N.W., Washington, D.C. 20009. Catalogs of books in print are also available from AGU.

Publication of the Antarctic Research Series has been supported by National Science Foundation grant DPP 80-19997.

Some statistics on antarctic serial literature

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The Cold Regions Bibliography Project at the Library of Congress continues to abstract and index literature on the Antarctic. More than 26,000 bibliographic entries have now been published and made available for online searching (through the System Development Corporation's ORBIT system) (cf. Smith 1978).

A recent count of serials and articles accessioned during the period July 1970–September 1981 shows that of 17,154 items abstracted, 13,665, or 80 percent, were journal (or serial) articles, published in 1,430 serials. Grouping the serials into three classes according to the average number of articles on the topic published each year, a system described by Bradford (1948), yields the following information:

- Serials publishing more than four articles a year—44 sources, 7,735 articles;
- Serials publishing more than one and up to four articles a year—319 sources, 4,189 articles; and
- Serials publishing one or a fraction of one article a year—1,067 sources, 1.741 articles.

Both Bradford's study, which focused on literature on applied geophysics, and this antarctic sample show considerable dispersion, illustrating the known fact that many articles on any given subject (or geographic region) are found in journals that contain such articles only occasionally. In fact, in the case of antarctic literature, the average number of articles per serial title was 9.55, or less than one per yea. over the period studied. Moreover, 658 serials carried only one pertinent article, and another 428 serials only two pertinent articles. Consequently, the median number of articles per serial is 1.08 for the 11-year period, that is, fewer than one every 10 years.

Speaking of this kind of dispersion, K. C. Owen (1974) concluded: "It is apparent that secondary services . . . or outside scanning services are necessary to provide more complete coverage . . . than is obtainable with one's own resources" (p. 432). The problem is accentuated by shifts in subject emphasis, as noted by Amacher, Berninger, and Bates (1974) in an article on journal productivity in a mission-oriented field, and by Thuronyi (1979). In the Cold Regions Bibliography Project, regular scanning of journals is supplemented by such methods of data acquisition as computer searches of online databases, checks of published bibliographies and reference lists, and receipts from authors, publishers, and the project sponsor.

Listed in the table are the 44 serials that over the study period average more than four articles a year relating to the Antarctic. Also given are the total numbers of articles for the 11-year period. It goes without saying that this purely quantitative listing does not provide a measure of the usefulness or quality standards of the journals. Furthermore, because some of the sources have not been productive over the entire 11-year period, the figures are not necessarily directly comparable.

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Number of articles relating to Antarctica published between July 1970 and September 1981 by serials averaging more than four articles per year, by rank

Rank	Serial	Number of articles
1	Antarctic Journal of the U.S.	1,681
2	Sovetskaia Antarkticheskaia Ekspeditsiia. Informatsionnyĭ biulleteń	544[a]
3	Antarctic Record, Tokyo	395
4	Journal of Geophysical Research	353
5	Sovetskaia Antarkticheskaia Ekspeditsiia. Trudy	324
6	Nature	309
7	Polar News (Kyokuchi), Tokyo	293
8	British Antarctic Survey. Bulletin	278
9	National Institute of Polar Research, Tokyo. Memoirs	273
10	Antarctic, Wellington, New Zealand	229
11	Polar Record, Cambridge	219
12	Arkticheskiĭ i Antarkticheskiĭ Nauchno-Issledovatel'skiĭ Institut. Trudy, Leningrad	202
13	Antarctic Research Series, American Geophysical Union	148
14	Initial Reports of the Deep Sea Drilling Project, Scripps Institution of Oceanography, La Jolla, Calif.	136
15	Journal of Glaciology	120
16	Earth and Planetary Science Letters	118
17	Contribución (or Contribuciones Científicas), Instituto Antártico Argentino, Buenos Aires	117
18	Science	116
19	Antarktika: Doklady Komissii	104
20	New Zealand Journal of Geology and Geophysics	102
21	Publication. International Association of Hydrological Sciences	98
22	Comité National Français des Recherches Antarctiques, CNFRA	96
23	South African Journal of Antarctic Research	95
24	JARE Data Reports, Japanese Antarctic Research Expedition	94
25	Antártida, Buenos Aires	93
26	Problemy Arktiki i Antarktiki	85
27	Akademiia nauk SSSR. Institut Geografii. Materialy Gliatsiologicheskikh Issledovaniĭ	84
28	Pacific Insects	80
29	Deep-Sea Research	77
30	Oceanology (trans. of Okeanologiia)	76
31	Dry Valley Drilling Project. Bulletin	75
32	Journal of Atmospheric and Terrestrial Physics	73
33	Geomagnetism and Aeronomy (trans. of Geomagnetizm i Aeronomiia)	72
34	Planetary and Space Science	68
35	Notornis	60
36	Annales de Géophysique	58
37	Geological Society of America. Bulletin	58
38	Akademiia nauk SSSR. Institut Okeanologii. Trudy	55
39	TAAE, France	54
40	U.S. Antarctic Projects Office. Bulletin[b]	51
41	New Zealand Antarctic Record	50
42	Informationen für die Fischwirtschaft	49
43	Vsesoiuznyĭ Nauchno-Issledovatel'skiĭ Institut Rybnogo Khoziaĭstva i Okeanografii. Trudy, Moscow	48
44	Akademiia nauk SSSR. Doklady	46

[a] Includes original and translated titles, with some overlap.

[b] Discontinued.

Earth and Ice: Antarctica as history and civilization

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I have undertaken a project in which, by a series of interconnected essays collectively titled "Earth and Ice," I will consider aspects of antarctic history and the civilization that has come to exist there. As history, the story, especially its latest chapter, symbolically inaugurated by the International Geophysical Year, is dominated by exploration. As a civilization, Antarctica has been controlled by the political economy of scientific inquiry. The Antarctic Treaty has confirmed these traits, perhaps indefinitely. My special interests lie in that most recent phase of exploration and in the history of scientific investigation into the solids of Antarctica, its earth matrix and ice cover. Antarctic history can be contrasted with the history of its northern conjugate, Greenland—the one remote from human penetration and Western civilization, and the other more-or-less related to them for more than a millenia. The contrasting political developments in these two regions after World War II well encapsulate these distinctions. Similarly, large-scale scientific research in Antarctica can be compared with more-or-less simultaneous inquiries into the deep ocean basins and interplanetary space. Discoveries in Antarctica have been significant in the remarkable revolution they brought about in the earth sciences, of which the theory of plate tectonics is the best-known expression but not the most important result. Ultimately, the outcome of these essays should be a description of how the ice, so long alien and inaccessible, became integrated with the earth and its human inhabitants.

A convenient way to think about exploration by Western civilization is to consider it in terms of three eras, each era focusing on somewhat different aspects of earth geography and each a part of a somewhat different intellectual and cultural movement. The first age of discovery began with 15th century Portugal, unveiled the world ocean, had as its grand gesture a voyage of circumnavigation, and culminated in the 18th century with a host of scientific circumnavigations. Its mode of discovery was maritime, first nurtured in Europe's interior seas, the Baltic and the Mediterranean. Captain James Cook's completion of the *mappa mundi* of the world's coastlines and his circumnavigation of the southern ocean were highlights of this period. Intellectually, the age coincided with the scientific revolution, best advertised by the adoption of the experimental method and the mathematicization of natural philosophy.

The second age of discovery evolved out of developments in the late 18th century. Beginning in Europe, and then radiating to the other landmasses of the Earth, geographic exploration began to unveil the interiors of the continents—not only their surfaces, but also their inner structure. The era's outstanding expression was the continental traverse. Intellectually, the era corresponded to the romantic revolution and the emergence of natural history, geology, and biology as premier sciences. The principal mode of integrating the new discoveries was not mechanical philosophy, but history. On the basis of concepts of development and evolution, a grand synthesis of earth, life, and social sciences took place. Antarctica was the last of the continents to be investigated, the drive for the pole replacing the transcontinental traverse. With the survey of the pole came the apparent answers to the intellectual questions that had sustained the earth sciences, the age and shape of the Earth.

Following World II, a third age of discovery emerged, one still very much active. Explorers moved into the deep ocean basins, interplanetary space, and Antarctica as sites for investigation. The International Geophysical Year (1957–58) was an appropriate announcement of a grand purpose: the geophysical inventory of a planet. If the first age of discovery compared oceans and littoral civilizations, and if the second age compared continents, indigenous cultures, and the records of vanished peoples and earth history, the third seeks to compare planets. The research for peoples has been replaced by a search for life itself. Intellectually, the period belongs to modernism, to a philosophic revamping of scientific etiology (the incorporation of chance), and to the collapse of historicism as a legitimate principal of explanation. New, too, is the perspective brought to bear by exploration. The first age had introduced oceans and maritime civilizations unknown to Europe. Similarly, the second age brought together into one geography the information acquired by hosts of peoples living on lands unknown to Europe. European culture and Western science provided an integrating mechanism by which to join these otherwise scattered lands and knowledge—but always there was a strong element of ethnocentrism to the concept of discovery. In the third age there is no ethnocentrism: these regions have always been uninhabited, unvisited, truly unknown. Exploration can come, for the most part, without colonization.

"Earth and Ice" will be the second of two complementary studies on the relation between the earth sciences and the three ages of discovery. "Dutton's Point: An Intellectual History of the Grand Canyon," a monograph published by the Grand Canyon Natural History Association, examines the traits of the first two ages as they relate to a great earth emblem of the 19th century. "Earth and Ice" will focus on the third age and center on an important earth emblem of the 20th century.

Support for this project comes from the National Endowment for the Humanities Antarctic Fellowship, with travel to Antarctica provided by the Division of Polar Programs, National Science Foundation. Research has included 3 months with USARP in Antarctica.

Antarctic Marine Geology Research Facility, 1981–1982

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Curatorial activities at Florida State University's (FSU) Antarctic Marine Geology Research Facility and Core Library during the year 1 June 1981 to 31 May 1982 have included the distribution of samples, the receipt and processing of new materials, and core-describing.

Sample distribution was as follows:

Eltanin: 2,746 samples from 306 different piston cores collected aboard 30 of the 47 coring cruises, 9 samples from 9 trigger cores of 7 cruises, and 2 samples from 2 Phleger cores of 2 cruises. Also distributed were 2 samples from camera-Campbell grab recovery stations of 2 cruises.

Islas Orcadas: 471 samples from 62 individual piston cores representing each of the five coring cruises (0775, 1176, 1277, 1578, and 1678) and 27 samples from 27 trigger cores of these cruises. (As of 31 May 1982, 21,634 samples had been distributed from the 459 piston, trigger, and Phleger cores recovered aboard ARA *Islas Orcadas*. A summary of *Islas Orcadas* coring appears in Cassidy 1980).

International Weddell Sea Oceanographic Expedition (IWSOE): 157 samples from 38 piston cores, 14 trigger cores, and 16 Phleger cores retrieved aboard the 1968, 1969, and 1970 IWSOE cruises of USCGC *Glacier.*

USARP 1975 (USCGC Burton Island): 1 sample from a bottom grab recovered in the eastern Amundsen Sea.

USARP 1976 (USCGC Glacier): 27 samples from 8 piston cores collected in the Ross Sea.

USARP 1978 (USCGC Glacier): 36 samples from 10 piston cores collected in the Ross Sea.

USARP 1979 (USCGC Glacier): 102 samples from 35 piston cores and 17 samples from 17 bottom grabs, all collected off the Adélie and George V Coasts.

USARP 1980 (USCGC Glacier): 675 samples from 160 piston cores and 20 bottom grabs retrieved from the antarctic coastal margin in the northwestern and southwestern Ross Sea.

USARP 1981 (USCGC Glacier): 95 samples from 12 piston cores recovered in the Amundsen Sea (8 cores) and Bransfield Strait (4 cores).

The 4,367 samples distributed, representing 44 cruises of four vessels, were received by 26 investigators representing 17 institutions in Australia, France, India, the Union of Soviet Socialist Republics, and the United States. (Not included in the sample distribution totals are 46 one-half sections of piston cores shipped on loan to a principal investigator and several hundred small samples that were removed from the cores for the preparation of smear slides used in core-describing.)

The wide geographic extent (figure) and variety of project materials sampled indicate that research interest in these materials remains high. An analysis of inventory records reveals that there were more separate requests this year than in past years. Also, the ratio of the total number of different cores sampled this year (736) to the total number of samples distributed from them (4,367) is greater than that of any previous year, and greater by a factor of 2.2 than the average value of this ratio for all years. These statistics are particularly useful in evaluating sampling effort during 1981–82.

The acquisition of new materials includes the June 1982 receipt of 311 meters of piston and trigger cores (167 cores) and 149 grab samples recovered at 205 ship stations of USCGC *Glacier* in waters adjacent to the northern Antarctic Peninsula and the South Shetland Islands. These specimens, collected during 1982 by John B. Anderson (Rice University), Paul F. Ciesielski (University of Georgia), and Peter N. Webb (Ohio State University), will be processed in preparation for a site visit by the principal investigator (Anderson).

Also received were approximately 75 kilograms of rocks collected by E. Imre Friedmann (FSU, Department of Biology) in the antarctic dry valleys.

Core-describing was completed of the 328 meters of piston and trigger core sediments retrieved aboard ARA *Islas Orcadas* in the South Atlantic sector of the southern ocean. Descriptions of these cores and their associated bag samples appear in Kaharoeddin and others (1982). This volume, the fifth and final volume in the series of sediment descriptions (Cassidy et al. 1977; Kaharoeddin 1978; Kaharoeddin et al. 1979, 1980) for materials collected aboard the five multidisciplinary cruises of this vessel from which cores were received at the FSU facility, completes the *Islas Orcadas* phase of the curatorial program.

Active participation by staff of the Antarctic Research Facility in core-describing projects of other institutions contributed to the publication of two volumes of core descriptions (Anderson et al. 1981; Kellogg et al. 1981) for sediments recovered during the IWSOE and USARP 1976, 1978, and 1979 cruises of USCGC *Glacier.*

In progress is core-describing of the approximately 370 meters of marine core sediments recovered during USARP 1980 and 1981. These descriptions will be published as issues of the continuing series of core description volumes produced by staff of the facility.

Curatorial work is supported by National Science Foundation contract C-1059.

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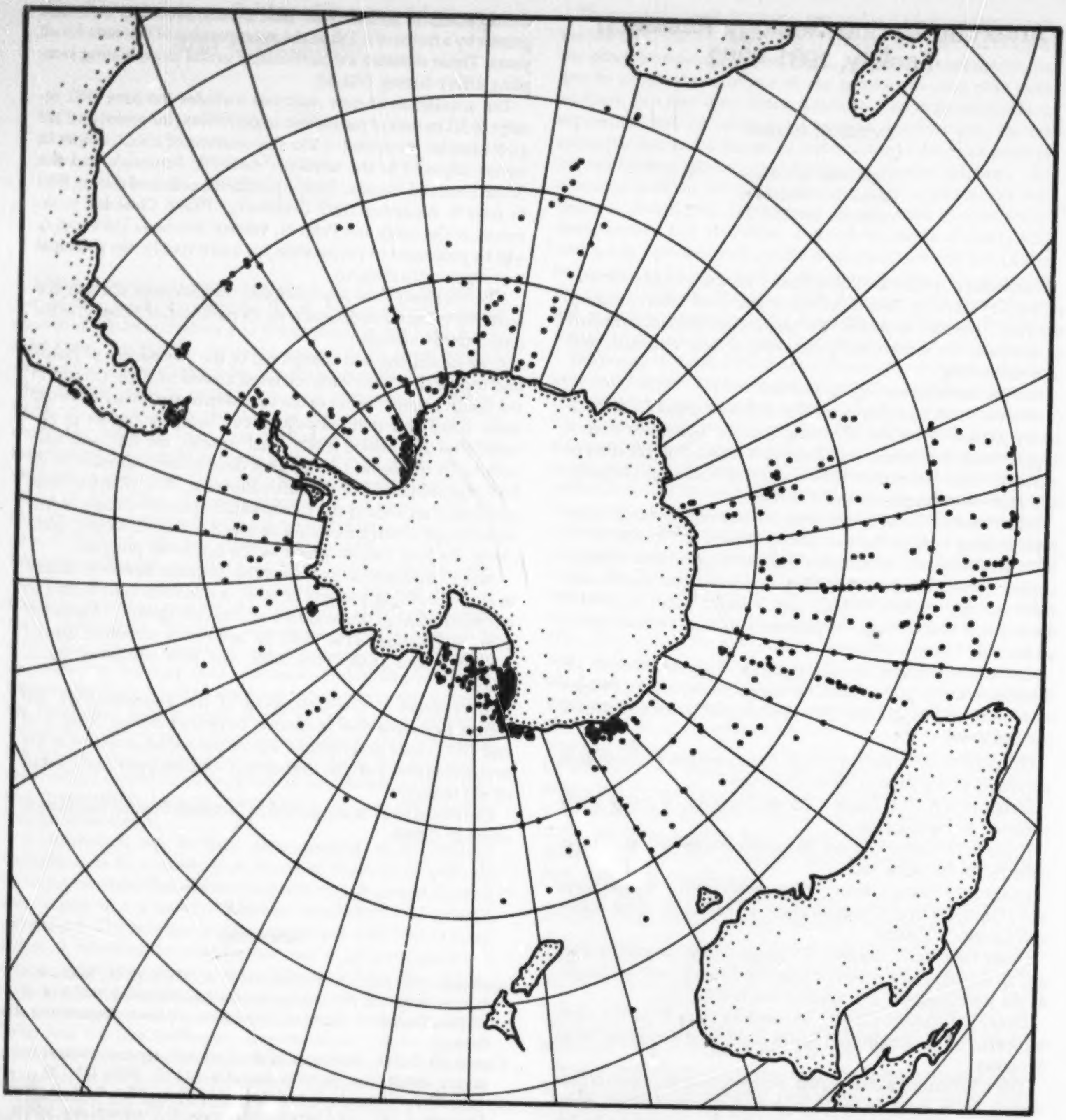

Geographic distribution of the 736 piston, trigger, and Phleger cores and bottom grabs from which samples were distributed during 1981–82. (Note: Not all station locations are shown as discrete points due to coring density in some areas.)

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Processing and systematic analyses of antarctic collections

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The Smithsonian Oceanographic Sorting Center (SOSC) is a processing and distribution center for biological collections. Its staff provides technical services to enhance and expedite systematic and other analyses of large and complex collections of organisms. Because marine biota typically is sampled nonselectively (except by size) by such devices as nets and grabs, a multitude of taxonomic groups may be obtained with each tow of nets through the water or across the bottom. At SOSC we sort, classify, and label individual taxa of concern to systematists, then prepare collections and ship them throughout the world for scientific analyses and publication of results by specialists. Biological projects under the U.S. Antarctic Research Program (USARP) have generated extensive and valuable marine collections from the southern ocean and adjacent waters for nearly two decades. In marked contrast to some major marine programs, the USARP has made some provision for analyses of this scientific resource. However, over the years most of the collections have been processed at SOSC; of the sorted and documented material, the largest portion has been distributed to approximately 250 specialists for study.

During the past year, approximately 1.3 million specimens were processed and were recorded in the antarctic computer database. Approximately 900,000 antarctic specimens in 9,700 lots from more than 7,000 samples were shipped to 60 specialists for analyses. In addition, collections returned by specialists were deposited in 24 herbaria and museums.

Zooplankton represented approximately two-thirds of the material processed. Although copepods from midwater trawl samples taken during USNS *Eltanin* operations in the southern ocean constitute a major portion of the zooplankton, they received little attention until recently. We now are sorting them to families or genera, and 10 specialists are studying various groups. Some completed studies already have been reported in the scientific literature, and others will be soon. Eucaridean crustaceans, which are ecologically and economically important in the polar ecosystem, also are receiving further attention, and the more definitively classified specimens have attracted new interest from specialists. Present work is focused on adult and juvenile euphausiids and co-occurring decapods. Numerous specimens of pasiphaeid and nematocarcinid caridean and aristeid and sergestid penaeid shrimps are available. Research on these groups, coupled with the results of completed or current studies of other major pelagic fauna, will make feasible the future analyses of community structures and interactions among different species in the polar ecosystem.

A wide variety of benthic invertebrates was shipped this year, including Actiniaria (sea anemones), Amphipoda, Ascidiacea (sea squirts), Brachiopoda (lamp shells), bryozoa (moss animals), Crinoidea (sea lilies), Copepoda, Echinoidea (sea urchins), Hirudinea (leeches), Holothuroidea (sea cucumbers), Komokiacea, Isopoda, Nemertinea (ribbon worms), Opisthobranchia (sea slugs), Ostracoda, Pelecypoda (clams), Porifera (sponges), Pycnogonida (sea spiders), Stomatopoda (mantis shrimps), and families of polychaete worms.

Sorting of benthic fauna was concentrated on preparing previously unavailable material. One project concerns organisms associated with other groups. An example is sponges, which frequently are inhabited by other animals, such as acanthozomadid amphipods. Most of the enormous antarctic sponge collection has been examined, and the inhabitants can be removed safely for sorting and distribution to other specialists. The yield from such collections benefits ongoing studies as well as new ones.

In part to augment certain current studies of antarctic benthic invertebrate fauna, Gordon Hendler, supervisor for benthic invertebrates at SOSC, received joint support from the National Science Foundation and the Smithsonian Institution to participate on cruise 82-4 of the R/V *Hero*. This was a cooperative effort with John Dearborn's group from the University of Maine (see Dearborn et al., *Antarctic Journal*, this issue). Dr. Hendler specially prepared invertebrates for specialists whose needs were not being met by extant collections. Preparations included special relaxation and fixation of some groups, freeze drying of others, and photography of color patterns of still others. Standard preservation of other collected groups yielded more than 300 lots of specimens from the cruise.

During the past year, SOSC staff continued efforts to refine and adapt procedures in order to attract new investigators to unstudied taxa. To expedite publication of research on collections, SOSC staff arranges subcontracts with some specialists, for limited support for technical assistance, illustrators, typists, and so forth. Eleven projects have been initiated this year. These include two projects covering five families of polychaete worms and projects on the copepod genus *Haloptilus*, choanoflagellates, scyphomedusae, nemerteans, siphonophora, five families of amphipods, angler fishes, midwater shrimps (Oplophoridae), actinians, and corallimorpharians.

Established investigators are encouraged to contact the Center's staff to discuss the availability of collections appropriate to their interests.

Processing of polar collections and maintenance of a centralized database are supported by National Science Foundation contract DPP 74-13988. The cooperative systematic studies are supported under National Science Foundation grant DPP 79-20835.

Reference

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Antarctic support operations

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This marked the second year ITT/Antarctic Services, Inc. (ANS) has provided specialized support for the U.S. Antarctic Research Program (USARP). During the 1981–82 season, ANS deployed 252 employees to six antarctic locations in support of 80 science programs being conducted by 269 National Science Foundation (NSF) grantees. The locations were McMurdo Station, inland stations at Siple and South Pole, major field camps at Dome C and in northern Victoria Land, and Palmer Station in the Antarctic Peninsula. ANS personnel also provided support aboard the research vessel *Hero*.

The ANS winter fly-in crew arrived in August 1981 to prepare for the 1981–82 field season. During August and September, ANS personnel, half of whom had had previous experience in Antarctica, supported six active science projects, completed preseason conditioning of USARP facilities at McMurdo Station and Williams Field, and launched an aggressive construction program. In addition, the following activities were accomplished.

McMurdo Station. The living environment was improved through partial rehabilitation of six "T-5" prefabricated, wooden buildings. In addition, foundations were prepared for a new water distillation plant. Scheduled to be online in 2 years, the plant will nearly double the amount of water available at McMurdo and should greatly enhance the quality of life at the station. Similarly, the power plant completed during the 1980–81 season assumed the total station load on 22 January. Williams Field, the McMurdo satellite facility on the Ross Ice Shelf for LC-130 aircraft operations, is also undergoing major improvements. Concurrent with relocation of the field, scheduled to commence during 1982–83, approximately 20 new living and working modules will be erected.

The Eklund Biological Center was very busy again this year. ANS personnel supported 15 projects related to biology, ocean science, and biochemistry. In addition, personnel at the Thiel Earth Science Laboratory and other McMurdo research facilities supported 23 geology, glaciology, and upper atmosphere research teams and handled storage and transport of Dome C ice cores.

Support activities at the Berg Field Center increased 25 percent over last season. It served as a major support center for planning, construction, and operation of the northern Victoria Land and Dome C field camps. Construction crews and research groups were outfitted and issued materials for projects put into the field by LC-130 aircraft.

In all, some 40 research groups were supported from the center, and 386 individuals were processed for snowcraft/survival training. With the deployment of a large amount of equipment to Seymour Island, the center succeeded in the first attempt to fully support research groups operating in the Antartic Peninsula region.

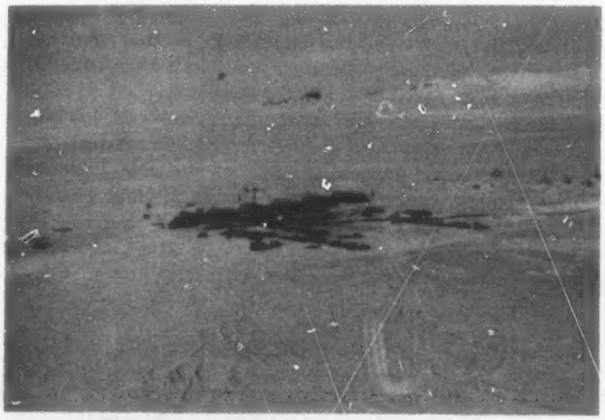
McMurdo Station began winter operations on 20 February 1982. A contingent of ANS employees was left to operate and maintain the new power plant to support several scientific programs from the Eklund Biological Center and the Berg Field Center and to prepare USARP facilities for next season.

Siple Station. A six-person crew arrived on 6 November to open the station, which had been winterized and deactivated at the close of the previous season. This experienced crew had the station and the summer camp operational within a week, but severe weather conditions hampered air operations and the research season did not begin in earnest until 3 December. In addition to supporting seven science projects involving 15 NSF grantees, ANS personnel erected a new 620-meter ionosonde antenna and a new satellite receiving antenna and reguyed and retensioned the Jupiter dipole antenna and transmission lines. The station commenced winter operations on 11 February 1982.

Amundsen-Scott South Pole Station. The station began summer operations after the first flight of the season on 5 November 1981. In addition to performing normal station operations, ANS employees provided support to 14 science programs involving 48 NSF grantees. Also, for about 10 days support and science personnel bound for the Dome C field camp stayed at South Pole Station for altitude acclimation.

The summer (emergency) camp generator system was rewired and load tested, and a stainless steel snowmelter was installed. Another major effort was the rehabilitation of the antenna farm. ANS employees replaced the coaxial cable to two antennas, the feedline to one antenna, and the structural support for another. Installation of a hydrogen generation system was begun and will be completed during the 1982–83 season.

Northern Victoria Land. ANS personnel erected a remote helicopter field camp in northern Victoria Land (NVL) (figure) in late October 1981. The camp was staffed by ANS employees and supported by the VXE–6 helicopter detachment, and was used by 63 scientists over the season. In mid-December, the camp provided transient berthing and assistance to the 41 persons rescued from the West German vessel *Gotlund II*. During the NVL camp's 90-day existence, a total of 4,752 worker-days were spent in camp, of which 2,836 were devoted to science projects, and the remainder to support functions. The camp was closed out and the equipment returned to McMurdo by 21 January 1982.



Northern Victoria Land field camp.

Dome C. This field facility on the east Antarctic Plateau was reopened on 20 November 1981. Operated by ANS, the camp supported continuing glaciological investigation of the east antarctic ice sheet by American and French researchers. The camp was deactivated on 28 January, and all major vehicles and equipment were returned to McMurdo.

Palmer Station. The 1980–81 winter crew was replaced by a new crew between 6 and 10 December 1981. During the austral summer an intensive marine biology program took place, involving nine projects and 34 NSF grantees. Laboratory space and aquarium facilities were extended to meet the expanded biology program. Summer season ended on 2 April. Two grantees, a medic from the U.S. Naval Support Force Antarctica, and five ANS personnel remained for the winter.

Research vessel Hero. R/V *Hero* entered drydock in Montevideo in mid-July for its annual refitting and then supported geological studies off the southeast coast of Argentina. The first cruise to Antarctica, in early December, transported the new Palmer crew and returned the 1980–81 crew to South America. The science season suffered no delays, and all cruises were conducted as scheduled. *Hero* departed Antarctica on 2 April 1982 for the last voyage of the season.

ANS support services were provided under National Science Foundation contract DPP 80-03801.

Feasibility of wind turbine/diesel hybrid generators at McMurdo Station

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The diesel-electric generators at McMurdo Station burn an average of 80 gallons of diesel fuel, arctic grade (DFA) an hour to meet the station's average load of 1,000 kilowatts. The boilers in the water desalination plant require an additional 20 gallons of DFA an hour, and the building heaters, 65. This adds up to approximately 1.5 million gallons of DFA a year. A study is under way to determine whether, for these energy needs (power, water, and building heat), wind turbine generators (WTG's) would be a feasible alternative to diesel generators.

A preliminary assessment has been made of the wind energy resource in the vicinity of McMurdo Station, at locations that are possible sites for large wind turbines. The assessment is based on (1) approximately 20 years of wind data recorded on strip-chart recorders in the meteorological center, using an anemometer mounted above the administration building at McMurdo, (2) 2 weeks of wind measurements at several sites near McMurdo, using a portable anemometer, a 10-meter-high mast, and a battery-powered cassette recorder (University of Arizona), and (3) 3 months of measurements on Star Glacier above McMurdo, using an automatic weather station with an anemometer mounted 3 meters above the surface (University of Wisconsin), and (4) various other measurements and information in the literature on the climatology of the Ross Island area. The sites around McMurdo where portable anemometer measurements were made were chosen because they were believed to be practical (primarily because of their accessibility) as WTG sites. (Locations of these sites are given in table 1, and the measurements taken at them, together with the measurements taken above the McMurdo administration building, are given in table 2.)

Measurements were made of the horizontal component of the wind speed, 10 meters above the ground, at these sites. The portable anemometer and instrumentation for recording and reducing the wind data consisted of the components shown schematically in figures 1 and 2. Data (continuous wind speed) for each run were recorded on individual cassette tapes. During the period 12–21 December 1981, roughly 100 runs (approximately 50 hours of data) were recorded. Data for run 7 are shown in figure 3.

In addition to the data recorded on the cassette tapes, spot checks of the wind speed at the beginning of each run were made from the analog readout of the wind speed meter shown in figure 1. Also, a TALA (tethered aerodynamically lifting anemometer) kite was flown at several of the sites, to check the wind direction and the turbulence at heights of between 50 and 100 meters. These kite flights gave evidence of wind flow

Table 1. Locations of wind survey sites

Site name	Elevation (feet)	Coordinates[a] (thousands of feet)	
		East	West
Gap I	206	1,770.3	4,453.9
Gap II	227	1,770.9	4,453.7
Star Lake	480	1,770.2	4,457.3
Transmitter	521	1,771.1	4,454.7
Dome Hill	505	1,768.5	4,457.4
Arrival Heights	426	1,766.9	4,457.4
Plateau	523	1,768.6	4,458.2
Crater Hill	987	1,772.9	4,457.4
Hut Point	40	1,766.2	4,455.0
Star Glacier AWS (Jimmy)	656	1,771.7	4,460.0
Administration building	62	1,768.2	4,454.4

[a] *Source:* U.S. Naval Oceanographic Office Chart H.O. 6712, *McMurdo Station and Vicinity* (3rd ed.). Coordinates are for the 1,000-foot Universal Transverse Mercator (UTM) Grid, Zone 58C, International Spheroid.

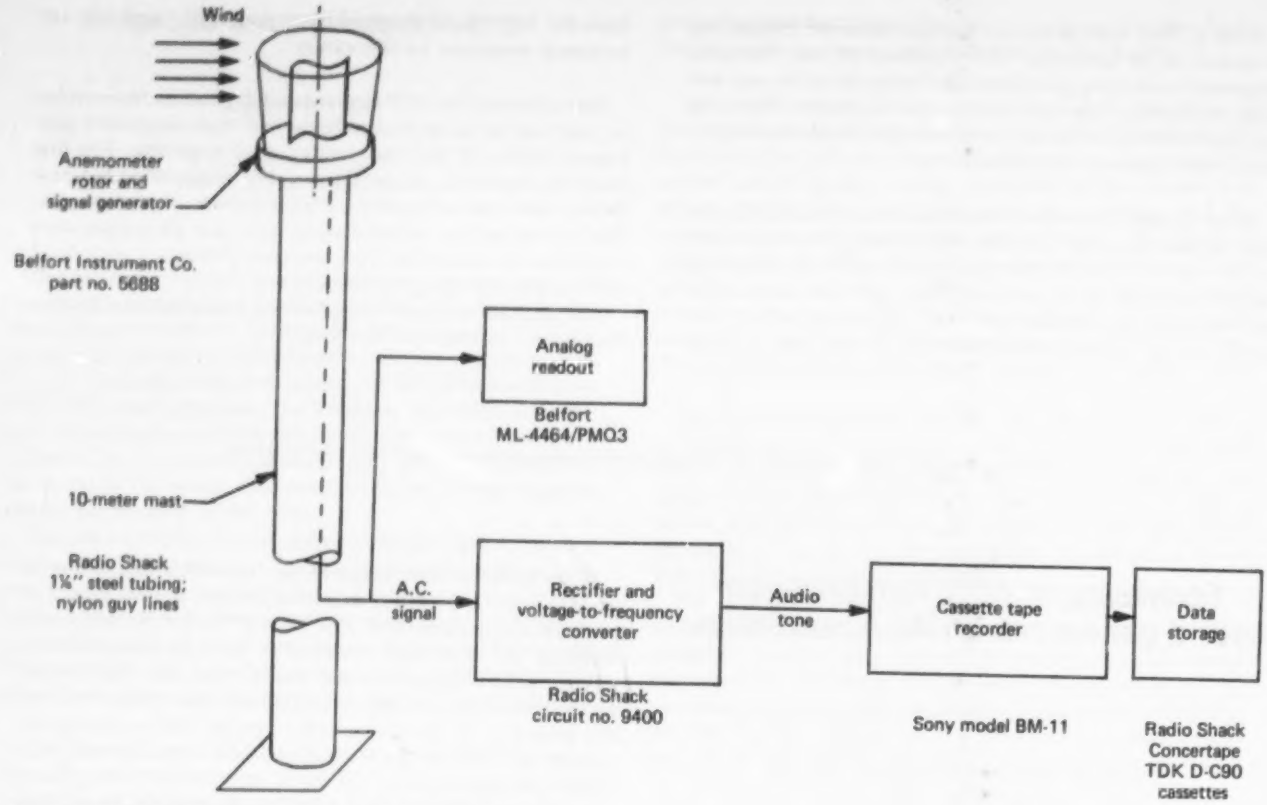
Wind
Anemometer rotor and signal generator
Belfort Instrument Co. part no. 5688
10-meter mast
Radio Shack 1⅞" steel tubing; nylon guy lines
Analog readout
Belfort ML-4464/PMQ3
A.C. signal
Rectifier and voltage-to-frequency converter
Radio Shack circuit no. 9400
Audio tone
Cassette tape recorder
Sony model BM-11
Data storage
Radio Shack Concertape TDK D-C90 cassettes

Figure 1. Portable anemometer and wind data recording system.

separation and severe turbulence at the crest of the site at Arrival Heights and showed that the flow through "The Gap" is relatively free of terrain-induced turbulence above approximatey 30 meters. The data in the table indicate that the wind speeds at 10 meters above the ground, at potential WTG sites in the vicinity of McMurdo Station, are at least 50 percent higher than the wind speeds recorded at the administration building. It is not unreasonable, therefore, to expect an annual average WTG

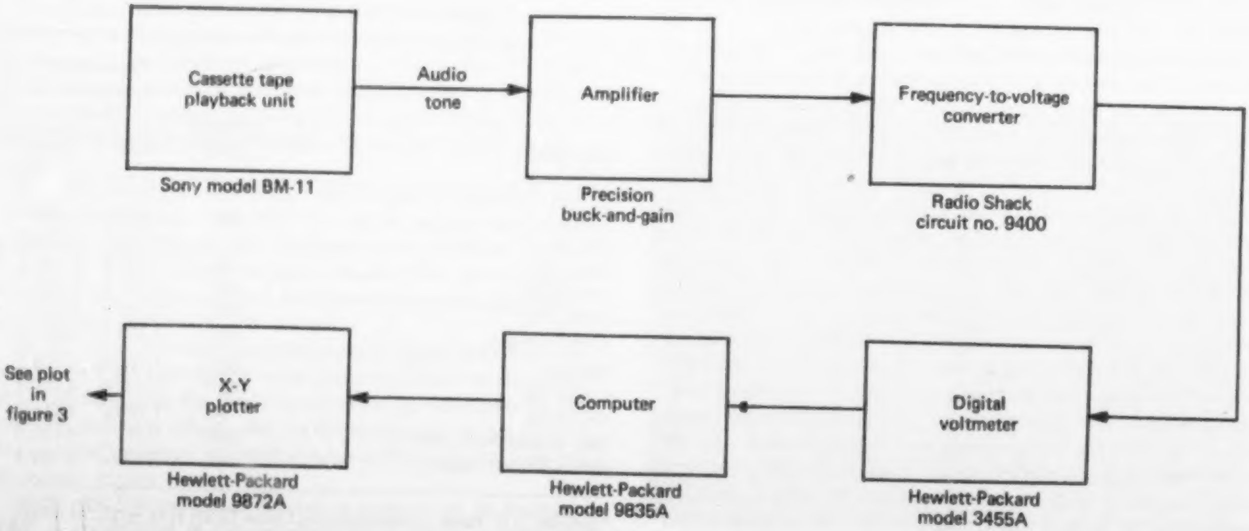
Cassette tape playback unit
Sony model BM-11
Audio tone
Amplifier
Precision buck-and-gain
Frequency-to-voltage converter
Radio Shack circuit no. 9400
Digital voltmeter
Hewlett-Packard model 3455A
Computer
Hewlett-Packard model 9835A
X-Y plotter
Hewlett-Packard model 9872A
See plot in figure 3

Figure 2. Wind data reduction system.

Table 2. Speed and direction of wind at possible wind turbine generator sites and above the McMurdo administration building

Potential WTG site	Date (1981)	Time (Greenwich Mean Time)	Site		Administration bldg.		Standard deviation
			Average velocity (Knots)	Direction	Average velocity (Knots)	Direction	
Gap I	12/21	21:46	14.26	N	9	N	2.05
Gap I	12/21	22:33	13.20	N	8	N	1.41
Star Lake	12/22	03.20	11.68	N	6	NNW	1.61
Star Lake	12/22	04:07	11.62	N	7	NNW	1.17
Dome Hill	12/22	21:21	15.71	NW	10	N	1.13
Dome Hill	12/22	22:03	17.10	NW	10	N	.85
Dome Hill	12/22	22:52	16.92	NW	10	N	1.28
Arrival Heights	12/23	01:28	16.62	NW	9	N	1.40
Arrival Heights	12/23	02:13	18.08	NW	9	N	1.03
Plateau	12/23	03:36	13.75	NW	8	N	1.34
Gap I	12/23	17:02	7.30	NW	3	NW	1.26
Gap I	12/23	22:27	5.90	W	1	W	1.29
Gap II	12/24	22:48	4.74	E	4	NW	1.48
Gap II	12/25	02:11	10.28	W	6	NNW	1.28
Gap II	12/25	05:50	9.66	NW	6	NNW	1.54
Gap II	12/25	08:23	9.34	NW	5	NW	1.08
Gap II	12/26	22:58	13.36	E	8	E	1.93
Crater Hill	12/27	04:00	8.02	E	9	E	.84
Gap II	12/27	21:00	23.07	E	9	E	2.51
Gap II	12/27	21:45	15.57	E	9	ESE	1.51
Gap II	12/28	01:35	21.99	E	14	ESE	1.58
Dome Hill	12/28	21:17	5.40	NW	6	NW	4.47
Gap II	12/29	02:29	9.07	NW	6	NW	2.65
Gap II	12/29	07:15	15.37	E	10	E	3.27
Gap II	12/31	00:42	10.97	ENE	9	E	1.75
Gap II	12/31	04:16	18.34	ENE	14	E	1.11

site wind speed of 9 to 10 meters per second; a very conservative estimate of wind speed at the administration building would be 6 to 7 meters per second.

In summary, it appears from this preliminary examination that generation of electricity by wind turbine generators would be feasible, at least in some respects. An excellent wind resource and adequate generator sites are available. Large WTG's could be used in conjunctijon with existing diesel generators.Finally, large WTG's have demonstrated good reliability and maintainability in environments similar to that of McMurdo Station.

I must emphasize that these conclusions are preliminary and subject to verification through further site screening, wind measurements, and consultation with WTC manufacturers. In addition, it has not yet been determined whether WTG's would be compatible with the electromagnetic environment.

This research was supported by National Science Foundation contract DPP 81-08420. Field personnel were the author and research assistant Robert D. Watters; instrumentation was developed by Walter Wrigglesworth and James L. Blair.

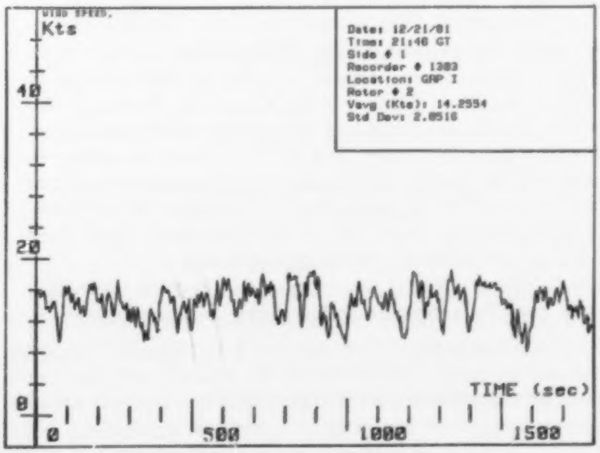

Figure 3. Run 7 output: Speed vs. time.

U.S. Navy Antarctic Development Squadron Six activities, 1981–1982

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The U.S. Navy Antarctic Development Squadron Six (VXE-6), assigned to provide airlift support for the U.S. antarctic program, began its 27th season with the "winter fly-in" (WINFLY) on 19 August 1981 when three LC-130 aircraft departed their home station in California for Christchurch, New Zealand. Enroute it was learned that fuel at American Samoa was contaminated, necessitating an alternate refueling stop between Hawaii and New Zealand. Fiji was selected as an alternate, and aircraft were serviced with minimal delay and proceeded to Christchurch.

The first three turnaround flights from Christchurch to McMurdo Station were flown on 24 August. Two additional flights were flown on the 25th, and the final flight took place on the 26th. Good weather and the superior efforts of all personnel enabled the accomplishment of all six turnaround flights in a record 3 days, making this a highly successful WINFLY.

The Navy's summer support season began 12 October 1981 when six ski-equipped LC-130 Hercules aircraft departed California for Christchurch, New Zealand. During the transit, one specially modified LC-130 conducted air sampling for Washington State University. Following 4 days of intensive preparatory maintenance for polar operations, the Hercules aircraft flew to McMurdo on 19 October. Prior to their arrival, four UH-1N Iroquis helicopters stored for the winter had been dewinterized and had begun local training missions. LC-130 training flights began on 20 October, and UH-1N science support operations began in the McMurdo area on 21 October 1981. Two days later, Vanda Station in the dry valleys was opened by UH-1N's and the initial put-in to the remote northern Victoria Land camp was accomplished by the LC-130's.

On 5 November, three UH-1N helicopters, led by an LC-130, departed McMurdo for the 600-kilometer flight north, over mountainous terrain, to the northern Victoria Land camp. These helicopters remained detached to the remote camp throughout the season, while the LC-130's continued to provide routine logistic support. In December one helicopter crashed and was grounded for the rest of the summer. There were no injuries, and science support was affected only temporarily.

During the next 2 weeks, Byrd surface camp, South Pole Station, and Siple Station were opened for the season. The skiway at Siple was particularly rough, and this contributed to mechanical problems for the opening flight. It was repaired with the assistance of a crew brought in on a special maintenance support flight.

The season's only flight to Australia's Casey Station took place on 7 November. The LC-130 delivered needed supplies and personnel despite a rough skiway. After the visit, the aircraft flew over the Totten and Vanderford Glaciers, an area of Antarctica over which squadron aircraft rarely operate.

Dome C was opened on 20 November 1981. Soft snow necessitated jet-assisted takeoff for the aircraft's departure. It was also found that 2,420 meters was insufficient length for the skiway, and the problem was subsequently corrected by lengthening the skiway to 3,500 meters.

After the initial put-in at Siple, poor weather precluded any flights to the station until 6 December, at which time an all-out effort was begun to fill the winter diesel fuel requirements.

Once all outlying facilities were opened, VXE-6 Hercules and helicopters worked at their usual pace to provide a full range of logistical and scientific support. Operations went smoothly with the cooperation of unusually fine weather. In early December, several helicopters were grounded for 6 days after the discovery, during routine inspection, of cracks in the transmission area. Air New Zealand assisted to make expeditious repairs. Despite this minor delay, support continued on schedule. LC-130 aircraft transported fuel, cargo, and personnel to the various stations, and helicopters provided local science support in the McMurdo area, the Allan Hills, and the dry valleys. UH-1N helicopters were instrumental in the success of field parties at northern Victoria Land camp, flying more than 600 hours in support of approximately 55 scientists and field workers.

A tragedy brought squadron aircraft to the rescue. In late season a West German research ship, the *Gotlund II*, became trapped in sea ice and began to be crushed. An LC-130 airdropped pumps to the stricken vessel, but the ship could not be saved and its crew was evacuated to northern Victoria Land camp. Hercules aircraft assisted by transporting the weary crew to McMurdo and later to Christchurch.

The final helicopter flights were flown on 4 February. South Pole Station was the last outlying station to be closed out by an LC-130, on 10 February. Summer close-out of McMurdo on 20 February completed flight operations for Deep Freeze 82. Altogether, squadron aircraft had transported 2,252 passengers, 2.8 million pounds of cargo, and 463,000 pounds of fuel products during the season. All operational commitments were met ahead of schedule, in fewer than the allotted flight hours; UH-1N helicopters flew 1,541 of 1,611 available hours, and LC-130 aircraft 3,539 of 3,842 budgeted hours.

On 22 February, VXE-6 personnel arrived home in California, having proudly completed another very successful season.

Detachment Christchurch, 1981–1982 season

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Detachment Christchurch
Christchurch, New Zealand

Support and service are the key words in day-to-day operations at the U.S. Naval Support Force, Antarctica, Detachment Christchurch. The detachment is a vital link in the logistic chain between the United States and McMurdo Station in support of the U.S. Antarctic Research Program.

From 1956 until 1960, the Detachment Christchurch facility was located in downtown Christchurch and flights to Antarctica were made from Wigram Royal New Zealand Air Force airfield. Since September 1960, the facility has been located at the Christchurch International Airport, 5 miles from the center of the city. The detachment includes a complex of barracks and supporting buildings, two hangars for VXE-6 and U.S. Air Force aircraft, and a communications site some 10 miles west of the airport. The current physical plant dates back to World War II and is leased by the United States from the Christchurch Airport Authority.

Under the command of Commander Wayne A. Jones, USN, some 45 U.S. Navy personnel and approximately 25 U.S. and New Zealand civilians operate this key complex year around. The detachment provides a wide variety of support and services to the naval support force organization and to transient personnel on their way to and from Antarctica.

The detachment also functions as a cargo staging and movements center for Antarctica. Transit pesonnel, after being assigned berthing on base or in town, are fitted with polar clothing. The base complex can accommodate up to about 250 people, and up to 200 can be fed at any one time in the galley.

Other base facilities include two clubs, a small Navy exchange and commissary, laundry facilities, a modern dispensary, and a Fleet Post Office.

The bulk of the propriety cargo needed at the U.S. stations in Antarctica is flown south on aircraft departing from Christchurch. As part of a U.S.-New Zealand reciprocal agreement, a small unit of New Zealand military personnel assists with the detachment's air cargo operations in Christchurch during the summer season. Under the direction of Detachment Christchurch personnel, other food and supplies, including heavy machinery in transit to Antarctica, are loaded aboard ships at the seaport of Lyttelton, located 13 miles from the detachment.

The distance from Christchurch to Antarctica is about 2,100 nautical miles; the trip takes 8 hours on the LC-130 Hercules and 5 hours on the Air Force C-141 Starlifter.

Detachment Christchurch's activities during the austral winter are described in an "End of Season Report," copies of which are available from Detachment Christchurch, FPO San Francisco 96690 and from CNSFA (Commander, Naval Support Force, Antarctica), Port Hueneme, California 93043.

Aviation forecasting for the U.S. antarctic program

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The United States has been preeminent in aviation history in the Antarctic. From the early days of exploration, when Rear Admiral Richard E. Byrd executed the first flight over the South Pole, until the present, when continental flights are routine, adverse weather conditions have been the hazard to be reckoned with. Over the years, in slow and sometimes painful steps, progress has been made in weather forecasting. The first steps were the establishment of the science of climatology and the documentation of recurring weather events in the hopes of identifying patterns of weather change. Satellite coverage of the continent began in the 1960's and has improved over the succeeding years, giving forecasters a significantly greater capacity to produce accurate forecasts, especially those used for flight operations. With satellite coverage, meteorologists were, at last, able to observe the weather all along the flight path, a major improvement over their former reliance on reports from the network of observation stations scattered over the antarctic region.

Supporting the numerous flight operations now characteristic of the U.S. antarctic program requires sophisticated approaches. On any given day, the flight schedule at the U.S. advance base at McMurdo Station shows movement of every available aircraft. Flights destined for South Pole, Siple, and Byrd Stations depart in rapid succession. Interspersed with these are photo reconnaissance missions, training flights, and flights to and from Christchurch, New Zealand. Between October and mid-December, it is not unusual to receive two U.S. Air Force C-141 flights daily on turnaround missions from Christchurch. Adding further to the activity at McMurdo Station are local UH-1N helicopter operations in support of field camps. All these aviation operations combine to make McMurdo Station a hub of activity. Aside from mechanical difficulties, the weather is one of many factors weighing heavily on successful completion of flight objectives. Weather forecasts issued by the weather facility at McMurdo Station are, understandably, the object of much interest and attention.

Terminal aerodrome forecasts (TAF's) are issued by the meteorological watch officer at the McMurdo weather facility every 6 hours for Siple, Byrd, and South Pole Stations as well as for the ice runway/Williams Field skiway near McMurdo. U.S. Navy aerographer's mates (AG's) or trained civilian personnel at these stations supply the McMurdo weather facility with hourly aviation weather observations. These observations, which supplement 3- or 6-hourly synoptic observations, are passed to McMurdo Station via radio, sometimes being relayed by aircraft enroute. Balloon-launched radiosondes augment the observation programs at South Pole and McMurdo Stations, providing useful data on upper level atmospheric conditions. Campbell Island and Macquarie Island provide the only upper level data along the Christchurch–McMurdo flight track.

Prior to each mission, the aircraft commander is given a verbal flight briefing and packet of information. The briefing covers satellite imagery as well as the material in the flight packet. The packet contains a forecast of winds at flight level at several points along the route, which is used by the aircrew to determine flight time and fuel and cargo loading and to select possible alternate routes and/or flight levels. It also contains a forecast of weather conditions at the destination and at alternate destinations, forecasts of turbulence and icing along the route, and information on clouds, precipitation areas, and temperature.

Assembling this information is no small task. At least one flight forecaster is on duty around-the-clock. Moreover, the work associated with each flight does not end after the flight briefing. Weather personnel monitor the progress of each aircraft along its route through position reports. In addition, weather conditions reported by one aircraft are used in preparing forcasts for later flights. Working in close coordination with Navy air traffic controllers, the forecaster creates a continuous record of information for each flight.

Weather satellites are, by far, the forecaster's most useful tool. They are so important that three satellite ground receiving systems have been located in the McMurdo Station weather facility. The primary system is an advanced very high resolution radiometer/high resolution picture transmission (AVHRR/HRPT) system which was installed in 1979. This system provides resolution to one-third nautical mile and both visual and infrared imagery. The forecaster can alter the spectral display either by choosing one of six data channels from the satellite or by altering the gray shades in the imagery through modification of enhancement curves in the computer program that processes the satellite signal. A secondary ground receiving system, the scanning radiometer data manipulator (SRDM) can be operated simultaneously when two satellites are within range of McMurdo Station, or it can be used as a backup if the AVHRR/HRPT system is not working. The SRDM system also operates in visual and infrared modes, but at a lower resolution and with less capacity to alter the gray-shade enhancement of the imagery. A third system, the RO-402 shipboard receiving system, provides further insurance against loss of satellite imagery. RO-402 imagery is lower in resolution than either SRDM or AVHRR/HRPT data, but it can be used with confidence as a last resort.

In Antarctica, very little weather data can be obtained through direct observation. Weather satellites have been most useful in filling that void, allowing the preparation of believable analysis charts for regions both on and around the continent. Reliance on weather satellites is not the complete solution to the problem of paucity of weather data, however. Another approach to filling the information gap has been installation of automatic weather stations at several locations on the continent. These stations transmit wind, temperature, and pressure data to an orbiting NOAA or TIROS weather satellite. The satellite stores the data for later retrieval and, simultaneously, retransmits the data to any receiving station within range of the satellite's signal. The McMurdo Station weather facility is equipped to receive and process data received in this manner from the network of automatic weather stations that have been strategically placed in Antarctica. To assist in forecasting for the McMurdo area, a ring of eight automatic weather stations has been established around McMurdo Station at a radius of approximately 60 nautical miles. Information from these latter stations has become a valuable asset both to local forecasting and for ongoing research in polar meteorology.

Improvements in aviation forecasting services provided by the McMurdo Station weather facility and the smaller, but fully functional, detachment at Christchurch, New Zealand, are considered responsible in large part for increasing the success and safety of flight operations in the Antarctic. However, reliable forecasting in this inhospitable region remains a considerable challenge, even with modern equipment, and there is ample room for improvements. Future improvements most likely will be realized through installation of additional automatic weather stations, upgrading of communications facilities to speed delivery of data that quickly become outdated, and an increase in the amount of data collected on conditions throughout the Southern Hemisphere, with subsequent transmission of that information to weather forecasters at McMurdo Station.

Public works, 1981–1982

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The Public Works Department undertook four major projects during the past year, two at waterfront facilities and two at air operations facilities. One project, at Elliot Quay, involved inspection and planning for preventive maintenance. The other three were construction projects—installation of a new bridge, and replacement of Byrd Camp and the radar dome. The new methods and materials used in the construction projects represent a major improvement over those used for the original installations and should increase significantly the safety and survivability of the new structures.

Elliot Quay inspection. Following severe structural damage caused by a storm in 1972, the Elliot Quay steel wharf was abandoned and replaced by a floating ice wharf. Much of the steel debris from the original wharf had been left in place.

Figure 1. The U.S. Army vehicular land bridge, or scissoring bridge, installed at the McMurdo ice wharf transition ramp.

Although it was not considered an immediate danger to navigation, it seemed wise to survey the debris to identify the limits of safe approach to the Elliot Quay fast ice face. In February 1982, U.S. Navy Underwater Construction Team Two, from the Naval Construction Battalion Center, Port Hueneme, California, surveyed the entire length of Elliot Quay. In addition to identifying the underwater configuration of the abandoned wharf and locating the steel debris, the team discovered extensive undercutting of the ice face in the area of the ice wharf transition ramp. The undercutting was estimated to be about 6.1 meters deep. In 1983 a grid of timber pilings will be installed vertically into the undercut area down to the fast ice base. Once the water around the pilings has frozen, the pilings will be cut even with the transition ramp surface and the area will be topped with dirt. The resulting structure will provide satisfactory structural integrity in the undercut area for safe cargo movement to and from the ice wharf.

Scissoring bridge installation. Movement of the annual sea ice and significant changes in the position of the annual ice relative to the fast ice make it necessary to use portable bridges over the cracks in the transitions between fast ice and annual ice. In all prior seasons, these transition bridges were fabricated on site from steel "H" beams and heavy timbers. The bridges were very heavy and, although marginally portable, hard to handle. During the 1981–82 season, a U.S. Army vehicular land bridge, commonly called a scissoring bridge, was used as a transition bridge in McMurdo. Figure 1 is a view of the installed bridge. The scissoring bridge is particularly suitable for use in Antarctica because it is lightweight, is easy to assemble and install with ordinary tools, provides an 18.3-meter span, and will support loads up to 60 tons without intermediate supports.

Byrd camp replacement. In the past, the airplane refueling facility at old Byrd Station (now known as Byrd surface camp) consisted primarily of several oil-heated Jamesway tent structures, which provided shelter for personnel, and a system of bladders used for fuel storage. Because Jamesway structures are constructed with wooden flooring directly on the supporting surface, in this case, snow, and because high winds and drifting snow are common at Byrd, the Jamesway camp posed a constant challenge to the small Byrd crew—snow had to be removed from the Jamesway outside walls to avoid structural freeze-in. In addition, the oil-fired heaters in the highly flammable Jamesway structures posed a serious risk of both fire and carbon monoxide poisoning. Crews in prior years had experienced all three problems. To avoid these problems, a new modular camp was constructed in 1982.

The new camp living area comprises six 3.66-by-7.32-meter modules mounted on 10-ton (9,072-kilogram) sleds. The advantages of the new structures and systems are many:

- Raised platform construction allows free air circulation below the modules, transfers heat away from the structure, halts freeze-in, reduces drifting, and allows sufficient elevation of sanitary outfall line for sanitary disposal at an adequate distance from the camp.
- Sled mounting makes it easy to maneuver individual modules and to relocate the camp as required.
- All-electric heat removes the danger of carbon monoxide poisoning in the living area.
- Exposed conduit electrical wiring throughout, use of fire resistant materials in construction, and installation of all-electrical components and heat-producing devices in accordance with the National Electrical Code and the National Fire Code reduce fire hazards to a minimum.
- Provision of a water supply module to include camp water storage separate from the snowmelter and the domestic water heater ensures an adequate supply of potable water and allows for purging and cleaning of any of the containers without a major interruption of the water supply.

Figure 2 is an end view of the newly constructed camp. In the foreground are the water supply module (light-colored structure) and the snowmelter assembly (small, dark module). The

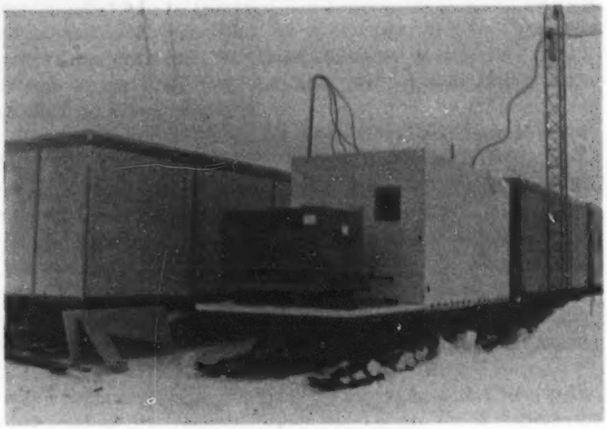

Figure 2. The new Byrd surface camp.

snowmelter is filled by front end loader. After one season in the new camp, the Byrd crew reported greatly improved comfort, reliability, safety, and habitability.

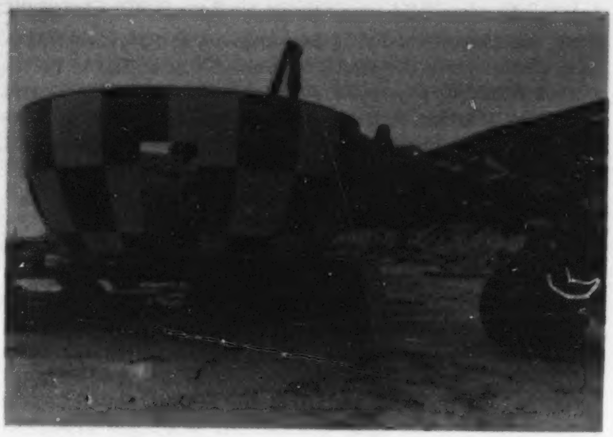

Figure 3. The new radar dome being erected on a modified 20-ton sled.

RADOME replacement. After extremely high winds destroyed the radar dome (RADOME) at Williams Field late in the 1981 winter-over period, two new fiberglass RADOME structures were procured. The new RADOME's are much more durable than the old one and are more than twice as large. Their larger size and weight necessitated a sled carriage significantly heavier (20 tons vs. 10 tons) and larger than the one used previously. This, in turn, necessitated the installation of heavy-duty outriggers and spread footings to counter the tipping effect created by wind force acting on the dome sail area.

Figure 3 is a view of a RADOME under construction and about 50 percent complete. It began operating at Williams Field in mid-December 1981 and has functioned satisfactorily since then. The second RADOME is scheduled to be erected during the 1982–83 season.

Ship operations

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Two U.S. Coast Guard icebreakers were under the operational control of Commander, U.S. Naval Support Force, Antarctica (CNSFA) during Deep Freeze 82—USCGC *Polar Sea*, from Seattle, Washington, and USCGC *Glacier*, from Long Beach, California. *Polar Sea* resupplied and refueled Palmer Station, performed channel break-in to McMurdo, escorted the dry cargo ship USNS *Yukon* and the tankship USNS *Southern Cross* into and out of Winter Quarters Bay, supported science projects, and called at Campbell island. *Glacier* called at Campbell Island, supported two phases of science in the Ross Sea, made two calls at Palmer Station, and provided science support in the Antarctic Peninsula area. This article describes icebreaker and supply ship operations in some detail and also describes briefly the activities of other ships operating in the area of Antarctica during Deep Freeze 82.

Ice conditions. Fast ice conditions in McMurdo Sound during the shipping season were essentially the same as those last season. However, Ross Sea pack ice conditions reportedly were the worst in 8 years; the northern pack ice did not open around the 180th meridian until mid-Feburary, about a month later than normal. Winds in McMurdo Sound generally were unfavorable during channel break-in and the remainder of the shipping season. More than 7 kilometers of the channel were filled with broken ice during the shipping season. (Subsequently, favorable winds did develop, and the area became ice free prior to winter freeze-in.)

Icebreaker operations. *Polar Sea* arrived at Port Hueneme, California, on 21 November 1981, and loaded 300 measurement tons of cargo and 120,000 gallons of diesel fuel for Palmer Station and R/V *Hero*. Cargo comprised general supplies and repair parts, foodstuffs (including dry, refrigerated, and frozen products), and hazardous materials. Two CONEX boxes were used on the port and starboard 01 weather deck to fulfill the hazardous cargo regulation requiring separation of noncompatible items. In addition, drums of gasoline were stowed in racks on the fantail. When loading was completed, on 25 November 1981, *Polar Sea* departed for Palmer Station, making port calls at Long Beach, Callao, Peru, and Valparaiso, Chile. In Valparaiso, fresh produce and gasoline were loaded, and civilian National Science Foundation and Antarctic Services, Inc., personnel and a U.S. Navy chief hospital corpsman embarked.

Polar Sea changed operational control (chopped) from COMPACAREA COGARD to CNSFA upon crossing 60°S on 2 January 1982 and arrived at Palmer the next day. The passengers disembarked and cargo and refueling operations commenced. The vessel anchored in Arthur Harbor with her stern approximately 107 meters from shore. Mooring close to shore kept the amount of hose needed to a minimum and allowed the hose to be suspended on the nonmoving pack ice. *Polar Sea* pumped ashore approximately 122,000 U.S. gallons of DFM (diesel fuel) in 12 hours. Because Arthur Harbor was 90–100 percent filled with ice, all cargo was taken to shore by R/V *Hero* rather than by *Polar Sea's* blunt-nosed LVCP's (landing craft vehicle personnel). Twenty personnel from *Polar Sea* helped station personnel handle the cargo ashore. Total time for cargo operations was 36 hours, and total time for *Polar Sea* at Palmer was 44 hours. The entire operation was conducted without incident.

Polar Sea departed Palmer on 5 January 1982 enroute to McMurdo. The automatic weather station at Lindsey Island was scheduled for pickup on an opportunity-only basis, but heavy ice conditions prevented pickup.

Polar Sea arrived at the fast ice edge, 23 nautical miles from Hut Point, on 15 January 1982. Vice Admiral James P. Stewart, USCG, Commander, Pacific Area (event V-11), boarded to observe icebreaking operations. Ice thickness was 1.5–2.5 meters, essentially the same as in previous years. *Polar Sea* made the run in and out with no difficulty. A different approach to channel cutting was attempted this season. The southbound leg was cut from close aboard Cape Royds to 1,371.6 meters abeam of Hut Point; the northbound leg followed a 322 degree T track to the fast ice edge, creating a large "V" cut. At the ice edge, the "V" cut was approximately 13 kilometers across. It was envisioned that with favorable southeast winds, the floe within the "V" would drift to sea, leaving a large open-water channel to Hut Point. Further, it was expected that as the season progressed and the ice east of the channel along the west side of Ross Island deteriorated, the floes that broke off would not block the channel and impede shipping. However, the traditional stationary lows of the Ross Sea were few and far between, resulting in generally unfavorable winds in McMurdo Sound, and the ice didn't move north. Subsequently, the ice within the "V" cut was crosshatched and the western leg was widened for use by ships during the next few weeks.

Glacier nested alongside *Polar Sea* on 16 January and transferred spare parts. *Polar Sea* tended the channel until 23 January, when she was diverted to rendezvous with *Yukon* at the northern pack ice edge for escort operations. During her return to McMurdo with *Yukon* close astern, in the vicinity of Cape Byrd and Beaufort Island, *Polar Sea* was stopped by a vast floe. *Yukon* attempted to avoid *Polar Sea*, but, due to her momentum and the narrow track into the floe, she could not. Her port bow raked *Polar Sea's* starboard side, and her bow reached *Polar Sea's* bridge wing before she finally stopped. *Polar Sea's* hull was ripped open, her flight deck nets severed, life lines bent in, mooring chocks knocked off their foundations, and after motor surf boat davits bent forward. *Yukon's* port bow plating had holes in several places between the frames. Fortunately, there were no injuries, and *Polar Sea* completed the escort on 28 January.

On 29 January, *Polar Sea* moored alongside *Yukon* in Winter Quarters Bay and refueled. Station refueling operations were completed late on 1 February, and *Polar Sea* assisted *Yukon* out of Winter Quarters Bay into the turning basin and then through the ice-filled channel to the fast ice edge. *Yukon* was advised that further escort would be provided but that there would be a day's delay while temporary repairs were made to *Polar Sea's* hull. *Yukon* elected to proceed without escort. On 2 February, she reported having torn a hole in her forepeak tank and requested escort to the open water of the Ross Sea. *Polar Sea* was directed to proceed and escort. On 3 February *Polar Sea* returned to McMurdo, commenced hull repairs, and discharged retrograde Palmer Station cargo.

With repairs completed on the 4th, *Polar Sea* was underway to rendezvous with *Southern Cross* in the vicinity of Beaufort and Franklin Islands. After escorting *Southern Cross* to Winter Quarters Bay on 5 February, *Polar Sea* departed for Ross Sea science support. Due to extremely bad weather, high winds, heavy seas, and icing, *Polar Sea* aborted a planned pullout of personnel from Cape Adare and scheduled another attempt for later. Cargo operations with *Southern Cross* were completed on 14 February; *Polar Sea* assisted her out into the turning basin, and both ships departed for New Zealand.

The following day, *Polar Sea* removed the three personnel from Cape Adare. Four days later she completed the Campbell Island passenger/cargo operation and headed for Wellington, New Zealand. *Polar Sea* arrived in Wellington on the 22nd; she departed on 27 February, chopped from CNSFA to COMPACAREA COGARD, and arrived in Seattle on 31 March 1982.

USCGC *Glacier* departed Long Beach enroute to Wellington (via Pearl Harbor, Hawaii, for refresher training) on 17 October 1981, with 0.68 metric tons of scientific cargo. The icebreaker arrived in Wellington on 23 December and chopped from COMPACAREA COGARD to CNSFA. In Wellington, personnel for several science projects and three persons sponsored by the New Zealand Department of Scientific and Industrial Research embarked for Campbell Island, and 1.4 metric tons (4.9 cubic meters) of cargo were loaded. In addition, some repairs were made and lube oil was taken aboard.

On 31 December, *Glacier* sailed from Wellington enroute to Campbell Island. Passengers and cargo were flown ashore on 3 January 1982, and *Glacier* departed for scheduled science support in the Ross Sea. Three persons and 0.55 metric tons (1.5 cubic meters) of equipment were put-in at Cape Adare on 9 January. *Glacier* completed her first science cruise on 16 January and nested alongside *Polar Sea* at the fast ice edge. Science parties were changed and *Glacier* departed to support science projects in the Ross Sea. An automatic weather station was installed on Franklin Island.

Glacier returned to McMurdo and worked the channel there from 24 to 27 January. She then loaded 16.2 metric tons (62 cubic meters) of equipment for science activities and for Palmer Station and departed on 29 January for Palmer Station with scientists and personnel from the National Science Foundation and Antarctic Services, Inc. On 8 February, a U.S. scientist was airlifted from the British station on Faraday Island. Later that day *Glacier* arrived at Palmer. Passengers debarked and cargo was offloaded, and other passengers and retrograde were taken on.

On 9 February *Glacier* departed for Punta Arenas, Chile, with a full load of passengers. She arrived there on 12 February, disembarked passengers, and embarked personnel for additional science projects.

Glacier left Punta Arenas on 13 February enroute to James Ross and Seymour Islands in the Weddell Sea. On 17 February, nine scientists and 4.2 metric tons of equipment were flown ashore. *Glacier* then departed to support other projects under way in the Weddell Sea and the Bransfield and Gerlache Straits.

Glacier made a second call at Palmer Station on 5 March and loaded 4.4 metric tons of scientific specimens and equipment. She commenced the pull-out of the geological field party on 7 March and departed for Punta Arenas the next day. *Glacier* chopped from CNSFA to COMPACAREA COGARD upon crossing 60°S on 11 March.

Passengers disembarked in Punta Arenas, and *Glacier* arrived in Long Beach on 21 April with approximately 20 metric tons of retrograde cargo and scientific equipment and specimens for further transport to Port Hueneme.

U.S. Coast Guard helicopter operations. Two aviation detachments from the Coast Guard Aviation Training Center (Mobile, Alabama) were assigned, AVDET 89 to *Polar Sea* and ADVET 88 to *Glacier*.

Resupply ships. The tanker USNS *Yukon* replaced USNS *Maumee*, which was scheduled to be used but was not ready. *Yukon* loaded product in St. Theodore, Greece, and arrived at McMurdo, under escort of *Polar Sea* from the northern pack ice edge, on 28 January 1982. *Yukon* discharged station fuel and refueled

Glacier and *Polar Sea*, then departed with the assistance of *Polar Sea* on 1 February. As noted earlier, in the vicinity of Beaufort Island she tore a hole in her forepeak tank and was escorted out of the ice by *Polar Sea*. *Yukon* stopped in Sydney, Australia, for repairs before continuing on. *Yukon* carried three passengers north. On the voyage the ship's cook died of an apparent heart attack.

USNS *Southern Cross* moored at Port Hueneme on 3 January 1982 and commenced loading the next day. Loading was delayed, and she did not sail until the 11th, 3 days behind schedule. She arrived in Port Lyttleton on 26 January. There, bad weather and longer than anticipated cargo-related operations caused an additional 3 days delay, and *Southern Cross* was 5 days behind schedule by the time she moored in Winter Quarters Bay, on 5 February. Cargo discharge and retrograde loading took 3 days longer than planned due to the record amount of cargo. On 6 February, a NAVCHAP BM1 was killed in an accident.

Carrying 173 northbound passengers, *Southern Cross* departed McMurdo under the assistance of *Polar Sea* on 14 February. On 20 February *Southern Cross* arrived in Port Lyttleton and commenced cargo and bunkering operations. She was ready for sea on the 22nd but was delayed for 2 days due to a New Zealand High Court Writ related to some cargo she was carrying. (The cargo was a helicopter that had been used in the German expedition to northern Victoria Land, and involved a salvage claim by the New Zealand national who had flown the helicopter off the sinking *Gotland II*.) Claiming sovereign immunity, the U.S. won the release of the ship and cargo, and *Southern Cross* sailed from Port Lyttleton on 24 February, arriving in Port Hueneme on 9 March.

Other shipping. The M/V *Lindblad Explorer* (Panama) had scheduled two antarctic cruises to McMurdo from Bluff, New Zealand, and the M/V *World Discoverer* had scheduled one cruise. Neither ship made it into the Ross Sea (let alone to McMurdo) due to pack ice conditions.

The M/V *Gotland II* (Federal Republic of Germany) began the season operating near northern Victoria Land in support of the German Antarctic North Victorialand Expedition (GANOVEX II). The 93-meter, 4,400-ton ship, which had an ice-strengthened hull, carried 41 scientists and crew and five Hughes 500 helicopters.

On 17 December 1981, McMurdo Station received a message that the *Gotland II* had become "beset in severe ice pressure" in Yule Bay, near northern Victoria Land, that several frames on the starboard side were bent, and that the ship was taking on water and listing. Later it was learned that all nonessential personnel had been taken by GANOVEX helicopters to a nearby coastal facility known as Birthday Ridge Camp, approximately 120 miles from northern Victoria Land camp. After a request for assistance, an LC-130 Hercules aircraft dropped two large-capacity discharge pumps (Gorman Rupp) and extra lengths of hose onto the ice near the ship. Before the pumps could be put into operation, the ship had listed severely and had flooded to the main deck. All hope of saving the ship was abandoned, and the remaining *Gotland II* personnel went ashore.

Initially, the *Gotland II* personnel were dispersed to the previously established Lillie Marlene Camp and two new temporary camps, Litell Rocks and Birthday Ridge. On 18 December the *Gotland II* sank. All personnel were flown to northern Victoria Land camp in GANOVEX helicopters, and then, during the following 2 weeks, to McMurdo via regularly scheduled LC-130 flights, for later transport to New Zealand. The five GANOVEX helicopters were ferried to McMurdo, then shipped aboard USNS *Southern Cross* to Port Hueneme.

Back cover. In East Antarctica at Dome C (74°30'S 123°10'E), U.S. and French glaciologists and geophysicists investigated the ice sheet during the 1981-1982 summer. These Jamesway huts, with wooden floors and insulated, sheltered the 15 scientists and 5 support personnel and housed supplies and equipment. Dome C, at 3,245 meters elevation, is the third highest region of the east antarctic ice sheet. (NSF photo by Russ Kinne.)

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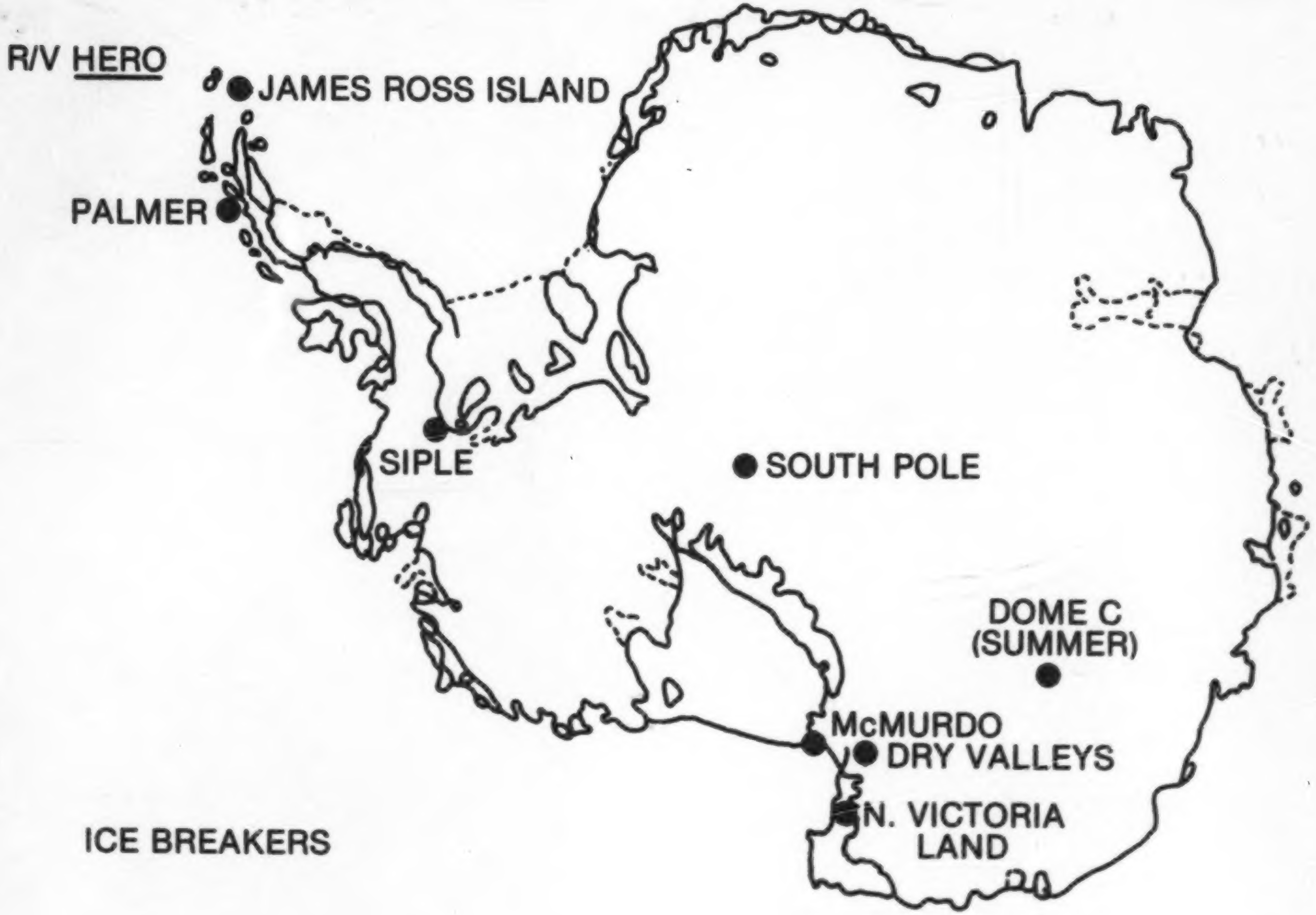
U.S. ANTARCTIC RESEARCH PROGRAM
1981-1982
LOCATIONS OF MAJOR ACTIVITIES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